EXPERIMENTAL STUDY OF AERODYNAMIC COEFFICIENTS ON HIGH RISE BUILDING MODELS

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19/4/89
B

CERTIFICATE

This is to certify that the thesis entitled, ''Experimental Study of Aerodynamic Coefficients on High Rise Building Models'', is a record of the work carried out under my supervision by Mr. Ashit Gupta and that it has not been submitted elsewhere for awarding a degree.

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(ASHIT GUPTA)

CONTENTS

ABSTRACT

The purpose of this study was to obtain a wider knowledge of the wind effects on the high rise rectangular building models for various angles of attack (or yaw angles) and for different width to breadth ratios of the model cross-section. Tests were conducted on models of four different cross sections with width to breadth ratios of 1,1.33,2 and 4 with the width kept constant at 10 cm. The models were mounted horizontally in a wind tunnel test section and forces and moments were measured using a 3- component aeronautical balance with wind speed varying from 20 m/s to 32 m/s. The Reynolds number during the entire study was kept between 10^4-10^5.

The variation of dragforce, lift force (side force) and pitching moment (yawing moment) of the models with wind-speed and angle of attack in the range of + 22.5° to -18° is presented. It has been observed that in the horizontal mounting, considerable asymmetry is induced into the flow around the models due to the presence of brackets and vertical struts used for mounting the models. Asymmetry may also arise because of the axial non-uniformities in the incident flow. Even in the face of such drawbacks the measured results compare well with the earlier studies done with vertical mounting and gives a good idea of forces and moments acting on high rise buildings under varying conditions.

LIST OF SYMBOLS

C_D	Drag coefficient
C_S	Side force coefficient (lift force coefficient)
C_M	Pitching moment coefficient (yaw moment coefficient)
D	Drag
L	Lift (side force)
M	Pitching moment (yaw moment)
ρ	Density of air
v	Wind speed
b	Breadth of the model
t	Width of the model
Re	Reynolds Number
α	Angle of attack
ν	Kinematic viscosity

LIST OF PHOTOGRAPHS

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 WIND ENGINEERING AND FORCES ON STRUCTURES

Wind loads on building and structures are of growing concern as the total yearly cost of damage to tall structures caused by the wind increases. Use of lighter frames for tall buildings requires that wind loading be specified accurately in the design process. Hopefully, a realible method of doing this is to test the scaled-down models of buildings in the wind tunnel. A considerable body of such data is now being incorporated in the building codes of a number of countries such as Canada, USA, Australia etc.

With the growth in research and testing activities in the field of wind engineering, the wind tunnel has become the primary tool for use in studying wind loading problems related to Civil Engineering. The study of wind loads on buildings is quite complex and hence efforts have been made to study the models at different levels of complexity. The simplest assumption commanly made in a wind building interaction study is to assume the building to have a two-dimensional form and the incident airflow to have a uniform mean velocity profile. This assumption obviates the measurement difficulties encountered in the three-dimensional flows which occur at the

base and at the top of the building and enables a study to be made which could be considered to be representative of the central region of the high rise structure. This type of study is of some value in assesing the way in which the forces on a building are influenced by its cross-sectional shape and by different height to breadth ratios.

The present motivation of doing a wind-force study on high rise building models comes from two sources- the increasing number of high rise buildings in our cities and also the availability of mechanical balance in the Aerodynamics laboratory.

The present study tried to demonstrate how a balance the has been designed for aeronautical purpose, can be used for studying forces on civil engineering structures as well.

The 3- component balance which was imported at a high cost for use in the Aerodynamics laboratory came in a damaged condition. The first task therefore became to bring the balance in the working condition. On observation it was discovered that the load transferring mechanisms for measuring the forces had been damaged. These were the solid brass cylinders attached with steel wires to the frame on one end and to the load cell on the other. To rectify them was a very important job and had to be done before the balance could be used.

These parts were refabricated and the load cells checked for response. Since it was not possible to press-fit wires of small diameters in the brass cylinders because of

lack of facilities, hence solid joints made of brass were used. This led to interference of lift in drag to a very low percentage,a correction for which has been incorporated in the observations.

1.2 LITERATURE REVIEW

Research in both natural wind and wind tunnel techniques during the past years has indicated the need for means of more realistic evaluation of both static and dynamic response of structures to natural winds. Studies on models of buildings and rectangular cylinders has attracted a lot of research and considerable of data is now available.

Akins and Peterka(1) have studied the mean force and moment coefficients for buildings in turbulent boundary layers. A series of thirteen different building geometries were considered and investigation carried out on effects of side ratio, aspect ratio, incident turbulent intensity etc. It was discovered that mean forces and moments for a series of rectangular buildings in a modelled atmospheric flow were found to collapse to reasonably similar curves when expressed in force and moment coefficient form. These curves were dependent on the side lengths of the buildings but were not a function of boundary layer characteristics. Also turbulence intensity had a marked effect on the forces and moments over a limited range of wind direction.

Lee (13) has studied the susceptibility of tests on two-dimensional bluff bodies to incident flow variations which may arise from axial non uniformities in the incident flow. It was reported that these non-uniformities could as well arise from introduction of mesh grids for generation of turbulence suitable for simulating the natural winds. This led to swift changes in wind directions and fluctuating readings will result. One way out is to take mean over a number of readings.

Krome and Sockel (16) made measurements of extreme drag coefficient of building model. Extreme Drag Coefficient is calculated with the help of C_D and the wind velocity at the extreme gust conditions which occurs for 2-5 secs and whose magnitude can be extracted from the meteorological data. However, since gust is affected by the local terrains and a large distance lies between building and the weather station and also because the effect and the magnitude will be lowered in a cluster of buildings - mean velocity is a more practical and realistic concept than the gust velocity to determine the extreme drag coefficient.

It was found out that extreme drag coefficients of different building models show mainly variations with cross section forms, and little infuence of height and of the type of the boundary layer.

Sakamoto (14) has done a study on aerodynamic forces acting on two square prisms placed vertically and reached the

conclusion that in the case of tandem arrangement the vortex shedding for the downstream prism was triggered by the arrival of vertices from the upstream prism when the distance between the prisms exceeded 3.5 times the prism width.

For side by side arrangements there was a regular pattern for C_D and C_L with the curve first dipping to a minimum and then rising as the gap between the prism increases. Such a study is helpful in investigating a group of building and wind forces acting on them.

Jancauskas(17) has tried to determine a frequency based transfer function which relates the velocity fluctuations to transverse force fluctuations. Sears functions is a convinient transfer function to determine such relationship for airfoils but when applied to rectangular cross sections it increasingly underestimates the forces as chord to thickness ratio of the section decreases. He therefore, made empirical changes in the Sears function to make it applicable to rectangular cross-sections. A possible explanation can be that Sears function assumes attached flow to a much larger chord distances (as in an unstalled airfoil), while in rectangular cross-sections with sharp edges, the flow separates much earlier.

Kawamura (15) did experiments on a full scale tall building and model tests too were carried out in a wind tunnel to study the wind characteristics around the base of a tall building. A comparative study was made between the actual

building and the model so as to determine the reliability of model tests by making some allowance for the correlation between them. It was found that wind velocity ratios in a model test seem to be in accordance with those in the full scale. The ratio shows an increase beyond the half width of the building when the wind is somewhat parallel to the measuring points. The ratio shows a decrease at the mid point and a rapid increase beyond it. In the model tests the large wind velocity ratios do not tend to appear in the latter half. For the wind velocity ratio the results from model tests are slightly higher than those from full scale tests.

Considerable work too has been done on wind loads on low rise buildings and the effect of wind on cluster of buildings.One such study is by Tieleman and Reinhold (11). There are other factors too affecting the wind flow around the building like trees. Nails and wooden pieces have long been in use in the wind tunnel to induce the effect of trees at the base of the buildings. Hanby (12) has suggested the use of wire mesh wound around a circular rod to simulate the effect of trees .With these the results were found to be in reasonable agreement with a series of full size wind velocity measurements and the models have proved useful where presence of trees has some definite influence on wind effects on the building.

1.3 SCOPE OF THE PRESENT WORK

In the present study the objective is to study the drag force, lift force (side force) and the pitching moment

on the building models at various wind speeds and varying angles of attack. For this purpose four models are being used-height and width of the modelsis being kept constant while the breadth is varying. The models are being mounted horizontally with one end inside the partition in the wind tunnel to simulate the ground. A 3- component balance designed for aeronautical purpose is being used to measure the forces on the model.

CHAPTER 2

EXPERIMENTAL EQUIPMENT

2.1 WIND TUNNEL AND ITS MODIFICATIONS

The subsonic wind tunnel (known as 5-D tunnel) at aerodynamics laboratory was used. It is a closed circuit type having a rectangular cross section of 915 mm x 610 mm with a length of 1675 mm. The characteristics of the motor are as follows:

	SCR	DC	Blower Drive
	Twin		15 HP
Input	400V	50 cycles 3 ∅	
	57-98-57 amperes		
Output	Armature 115V	110 ampere DC	
	Field 115V	5-7 ampere DC	

The motors are turned on by pressing the start buttons of respective units and their speed is then controlled by manual speed adjusting potentiometers. The maximum velocity obtainable is 42 m/s. For the installation of the model a 2 feet x 2 feet plexiglass partition was placed in the test section. The partition had a circular hole for fixing the wooden plate which had a rectangular groove in which the model was inserted.

2.2 WIND SPEED MEASUREMENT

For measuring the wind speed a pitot static tube was used. The pitot static tube was placed far upstream in the flow and the pressure measurements were taken by the water manometer inclined at 45^{o} with the ground.

2.3 3- COMPONENT BALANCE

The balance has two frames- one, with which it is attached to the supporting base and the other, which is movable and transfers the loads to the load cells. The load cells consist of high precision strain gages with excellent repeatability and linearity characteristics which measure the load which is displayed by the digital display.

The geometrical construction of the load sensing systems allows the complete seperation and independent measurement of the components of Lift, Pitch and Drag with negligible interactions of one component into another.

The maximum load that the balance can measure is as follows:

LIFT	-	120N
DRAG	-	60N
PITCH	-	2.5Nm.

CHAPTER 3

EXPERIMENTAL TECHNIQUE AND MODEL MOUNTING

3.1 STATIC CALIBRATION OF THE BALANCE

3.1.1 LIFT CALIBRATION

This is the simplest of the check calibrations and requires that no struts are fitted to the balance and that 1 Kg (9.78N) brass weights are added directly to the strut platform.

The balance is unclamped and by adjusting the rectangular tare weights the lift display is brought to read zero. Pitch and Drag too are brought to zero at the same time.

Now 1 Kg brass weights are added to the centre of the strut platform one at a time from 1–12 Kg. maximum, at each step the display reading is noted. (Assume the acceleration due to gravity to be 9.78 m/s^2).

Note: Any reading other than zero, present at the begining of the test before any load had been applied should be substracted from the display reading to obtain the actual load.

3.1.2 DRAG CALIBRATION

The three struts and the calibration model are mounted. Drag calibration pulley is positioned approximately

1 m. from the balance centre, downstream of the main struts. The groove in the pulley should be set to be parallel to the balance axis and at the same height as the central hole. Calibration wire is then attached to the model, passed over the pulley and then the weight hanger is hanged on its other end. Now the balance is unlocked and the tare weight system adjusted to give zero readings on all displays.

Now the weight hanger is loaded, 1 Kg at a time a maximum of 6 Kg and standard drag readings noted.

3.1.3 PITCH CALIBRATION

The three struts and the calibration model are mounted and the weight hanger is hanged from the model itself. Now seven 0.25 Kg. brass weights are placed on the middle of the strut platform. The balance is unlocked and readings brought to zero by tare weight systems. The balance is calibrated in the negative pitch by transferring one weight at a time from platform to the hanger. To calibrate the positive pitch the weights are initially placed on the weight hanger and transferred to platform one at a time.

The balance was then used to measure the forces on a 2- dimensional circular cylinder. The purpose of this test was to validate the working of the balance during the wind tunnel tests. The drag coefficient for cylinder was determined as 1.4, lift coefficient as 0.012. The cylinder

was mounted with the help of two main struts attached at the bottom of the main body of the cylinder. To attach the third strut a small tail about 5 inches long in the shape of the airfoil was attached to the cylinder. This generated small forces which were reflected in the readings the net lift force not being equal to zero. The results are given in the Appendix 1.

The balance was then used to measure the lift, drag and moment coefficient of an aircraft model as a function of angle of attack. The purpose of this test was to observe the working of the balance as well as produce standard results because the aircraft model was also to be used in the laboratory experiments. The results are plotted in figs.

3.2 MODEL FABRICATION

Four models were used to simulate the high rise buildings of different cross sectional shapes . The height of the models as well as the width were constant while the breadth varied, as shown below in the table

Height		61 cm
Width		10 cm
Breadth	a.	2.5 cm
	b.	5.0 cm
	c.	7.5 cm
	d.	10.0 cm

Hence four ratios of width/ breadth were achieved as

4,2, 1.33, 1.0.

The rectangular models were made from plywood and had sharp edges. Two small square grooves were made at the base of the models to accomodate the two plugging units to which the two main struts were added. The grooves were provided so that the part of the plugs may fit inside the body of the model so as to minimize flow disturbance due to mounting. The effect however will still be present because of sharp discontinuity that the remaining part presents to the flow.

A provision was made to attach the third strut to the model. For this purpose a threaded cylindrical rod, whose length could be adjusted was attached at the back of the model and it was fixed at one end with the nut and at the other end was placed the plug to which the strut could be attached. The same cylindrical rod was used in all the four models.

3.3 MODEL MOUNTING

The model is mounted on the balance in an inverted state if it is asymmetrical and can be mounted as a normal model if it is symmetrical. The reason for inverted mounting is that the lift is measured by the balance as the downward force applied on it.

The cylinder being symmetrical was mounted in a straight manner. The models of the building too were symmetrical and hence were not mounted inverted.

Usually in the works previously reported the models of the buildings were mounted on the base which was attached

to the base of the wind tunnel.

Since the balance that was used in the present study could measure the lift, drag and moment as it was designed for aeronautical purposes therefore it could not be used for study of forces on buildings in a routine manner. To overcome this difficulty a novel method was devised to mount the model of the building.

A vertical plexiglass partition was put in the windtunnel. It had a circular hole in it to hold a circular wooden plate. The model was now mounted sideways with the plexiglass partition simulating the ground. The wooden circular plate had a rectangular groove (about 5 mm deep) in it in which the model was inserted so as to disallow any free passage to air between the model and the plexiglass partition. A gap of about 3 mm was then left between the inner surface of the groove and the model so that circular wooden plate does not induce any effect on the forces on the model. The plate was made circular so as to facilitate rotation of the model to take measurements at varying angles of attack (yaw angles for building).

The speed was first varied keeping the angle of attack constant. It was then repeated for another angle of attack. Similar procedure was followed for all the four models.

3.4 UNCERTAINTY IN DATA

Static calibration was repeated to determine the reliability of the data. It was found that the maximum deviation from the standard value was approximately ± 1.5% . When the experiments conducted in wind tunnel were repeated it was found out the maximum deviation was ± 2% . Repeat tests were conducted on aircraft model and building model with square cross-section only.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 DATA REDUCTION

The force and moment coefficients were calculated as under :

$$C_D = \frac{D}{\frac{1}{2}\rho V^2\ bt}$$

$$C_S = \frac{L}{\frac{1}{2}\rho V^2\ bt}$$

$$C_M = \frac{M}{\frac{1}{2}\rho V^2\ bt\ (\frac{t}{2})}$$

ρ : air density

V : wind speed

b : breadth of the model

t : width of the model

(For moment coefficients, half chord is the reference point)

4.2 CALIBRATION RESULTS

After the necessary modification (as mentioned earlier) were made in the balance the calibration was done. It

showed that lift force was being measured by the balance correctly but there was difference in the actual value and the value being shown by the digital display for drag force and pitching moment. The difference was small for drag but substantial for pitch. However since the response of the balance to all the loads (lift, drag, pitch) was still linear, so correct readings could be extrapolated from the values being shown by the digital display . The required curves are shown in fig 6,7,8 .

4.3 FORCES ON BUILDING MODELS

The experiments were conducted at four wind speeds - 32, 30, 26 and 20 m/s. The height and width of the model were kept constant at 0.61 m and 0.1 m respectively while the breadth changed from 0.025 m. to 0.1 m in four steps.

The three aerodynamic coefficients C_D, C_S, C_M variation with angle of attack for one model at all the four wind speeds are presented on one graph sheet. The figs 12-15 present these data for 2.5 cm, 5.0 cm, 7.5 cm and 10.0 cm breadth models respectively. These aerodynamic coefficients are plotted again at the maximum and minimum test speeds for all the four models on a single sheet to show the variation of coefficients between different models.

It is observed from fig. 17 that the drag coefficient shows an increase with the increase in the magnitude of angle of attack for all models. For the model of breadth 2.5 cm

C_D is 1.95 at zero angle of attack and rises to almost 3 .0 at an angle of attack equal to 22.5^o, the wind speed being 32 m/s.

Similarly, at the wind speed of 20 m/s C_D is 1.4 at zero angle of attack and rises to 2.8 at an angle of attack equal to 22.5^o. From the same figures it is also concluded that drag coefficient increases as the breadth of the model decrease, more so for high angle of attack. For the wind speed of 32 m/s the drag coefficient at angle of attack equal to 22.5^o is almost 3.0 for the model with width 2.5 cm, 1.8 for the model with width 5.0 cm, 1.55 for the medel with width 7.5 cm and 1.45 for the model with square cross-section . At the wind speed of 20 m/s the drag coefficient at angle of attack equal to 22.5^o is 2.8 for the model with breadth 2.5 cm, 1.7 for the model with width 5.0 cm, 1.55 for the model with width 7.5 cm and 1.52 for the model with square cross-sections.

It has also been observed that for the model with square cross-section the variation of drag coefficient with angle of attack is relatively less than what it is for other cross-sections and this variation increases as the breadth of the cross section decreases (with width constant).

The drag coefficient at zero angle of attack lies between 1.25 and 1.75 for various models and a general conclusion that can be drawn from this data is that drag coefficient

decreases as breadth of the cross-section increases especially for high angles of attack. Broadly it is also observed from fig 17 that C_D is less at lower Reynolds number for particular angles of attack.

The side force coefficient v/s angle of attack curves show that while for the square cross section the side force coefficient is zero at zero angle of attack, it increases gradually to approximately 0.75 as the breadth of the cross-section decreases to 0.025 m. These facts are brought out by figs 12-15.

The side force coefficient at zero angle of attack shows little variation with Reynold's number. The dispersion of side force coefficient increases with decreasing cross-sectional breadth and these variations are marked for model with breadth 0.025 m especially at higher angle of attack. For the square cross-section the variation is less with Reynold's number for particular angles of attack and the maximum occurs at angles between 12^o and 15^o with magnitude at around 0.8. For the thinnest model of breadth 0.025 m the magnitude of maximum side force coefficient is almost 2.0 while for the model of breadth 7.5 cm the maximum side force coefficient is approximately 0.7, gradually decreasing to 0.1 at zero angle of attack again rising to 0.7 and then falling to 0.25 as the angle of attack is increased further to 22.5^o.

The side force coefficient at zero angle of attack is zero for model with square cross section and it gradually increases with decreasing breadth. However the curves also show that side force coefficient is not symmetric for positive and negative angles of attack. The possible explanation for this lies in the fact that the disturbance introduced in the flow due to brackets and struts is sufficient to destroy the symmetry of the flow and hence the side force coefficients are not same for same positive and negative angles of attack. This asymmetry can be reduced by placing the brackets inside the model to disallow any disruption in the flow. The destruction of symmetry of flow is one of the draw backs of the horizontal mounting.

The pitching moment coefficient v/s angle of attack curves have been plotted in figs 18 . For the building model with breadth of 2.5 cm the pitching moment coefficient gradually decreases from approximately - 1.0 at angle of attack equal to -18^{o} to zero at angle of attack -9^{o}. Then it again increases to - 1.35 at angle of attack equal to 12^{o} and then decreases to -0.3 as the angle is further increased to 22.5^{o}. The variation shows the same pattern for the building model with breadth 5.0 cm except that the moment coefficient now does not reduce to zero but a minimum value of 0.4 at angle of attack equal to -9^{o}. In contrast to this the pitching moment coefficient shows a much

less dispersion for the model with square cross section with the pattern of variation being same as that for other models. However one fact that emerges from the above figures is that moment coefficient is more at higher negative angles of attack.

The pitching moment coefficient is not zero even for the square cross-section. Infact the moment coefficient is always negative. The reason for this is that under the real test conditions the forces are not acting at the centre but are slightly off centre inducing moments. This action of forces is because of asymmetry introduced in the flow by the presence of brackets and struts. This asymmetry can be reduced by placing the brackets inside the model. Another asymmetry introduced is the tail that is attached to the model which joins it to the third strut. Although the effect due to it has been minimized by keeping the metal attachments inside the box but even the considerable asymmetry has been introduced with the forces not acting exactly at the centre of the cross section. Hence according to the sign convention being followed, the moment coefficient comes out to be negative.

CHAPTER 5

CONCLUSIONS

Calibration for the 3- component balance was done and its response to loads applied was determined to be linear. A circular cylinder was mounted in the wind tunnel and measurements taken with the help of the balance. Its drag coefficient was determined as 1.40 at Reynolds number equal to 10^5 and lift coefficient as 0.012. The experiments were also carried out on an aircraft model and lift, drag and pitching moment coefficients and their variations with angle of attack were determined. Experiments were carried out to determine aerodynamic coefficients (C_D, C_S, C_M) on models of high rise buildings by varying wind speed, angle of attack and breadth of the model (height and width being constant) A novel method of mounting models horizontally was used. The curves dropped to similar patterns for side force and drag coefficients but were more scattered for moment coefficients. It was also found that drag coefficient is less for square cross-section for one wind speed. Because of struts and brackets used for mounting the models there is considerable asymmetry induced in the flow which reflects in the results, but still the results were found to be in broad agreement with studies done using vertical mounting of the models.

CHAPTER 6

SUGGESTIONS FOR FURTHER WORK

The present work presents a simplified picture of what is quite complex phenomenon. Its importance lies in the fact that it presents a new technique for model mounting (i.e. sideways) so that aeronautical balances can be used to measure forces on civil engineering structures.

Further studies can be done on models representing various architectural designs that are taking over the building designs these days. Also important would be to study forces when a cluster of buildings are present rather than individual buildings . This would enable the researcher to study the effects of the neighbouring low/high rise buildings on other buildings. Further studies can also be done taking into consideration wind direction and speeds at different times of the year at a particular place. Such specific studies would give a complete picture of local wind forces.

It will also be of interest to observe the flow around such models using flow visualization techniques like smoke tunnel to get a better physical picture of the phenomenon.

Introduction of turbulence to simulate natural wind conditions is necessary to get a real picture of flow around buildings. Studies incorporating these aspects will also be important in this context.

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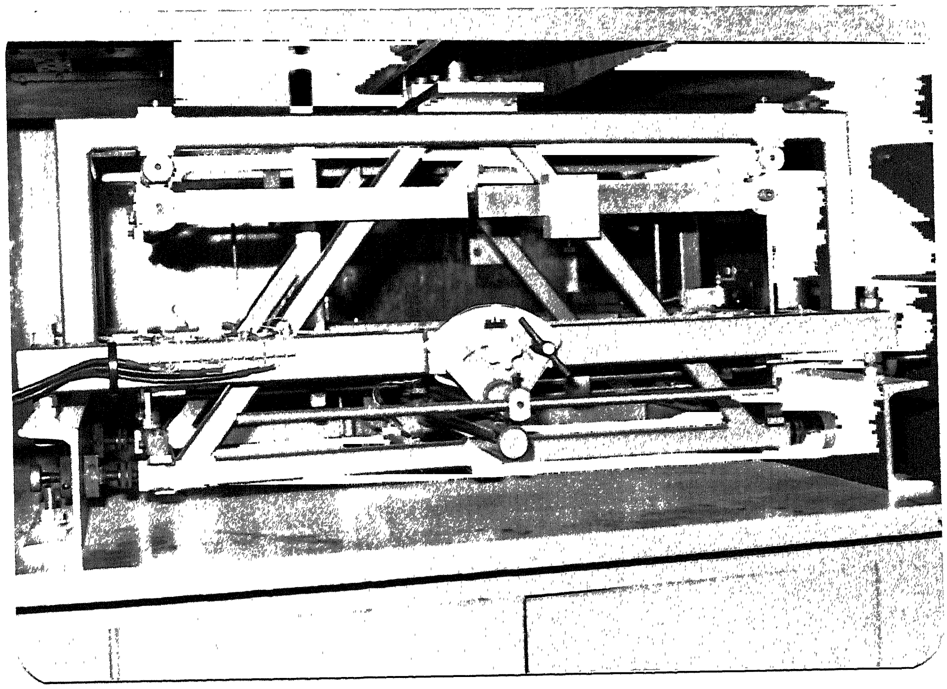
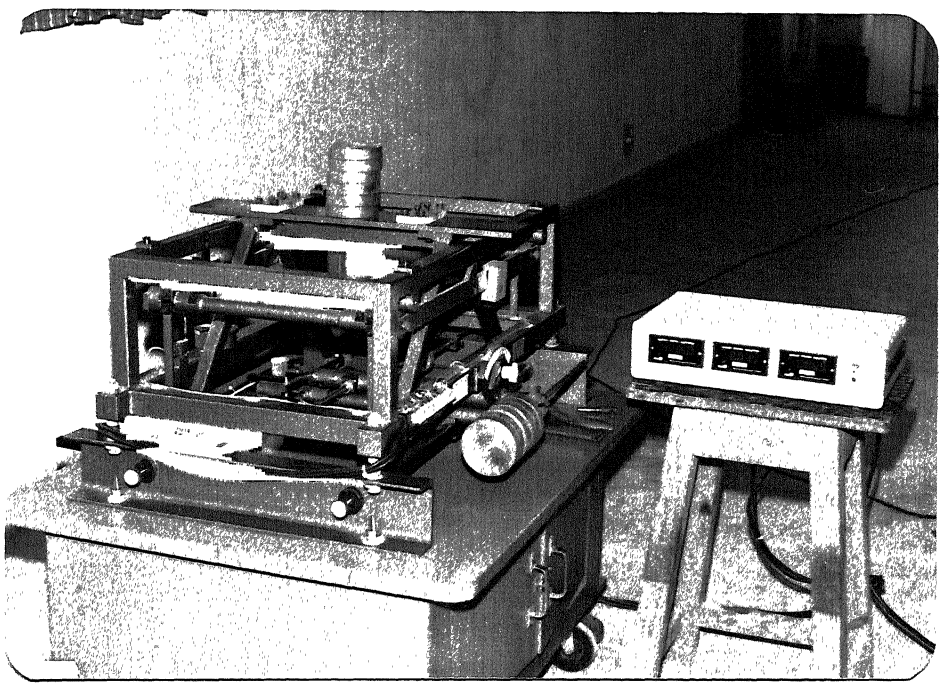
ADDITIONAL NOTE

The display was showing fluctuating readings as the forces, particularly the Drag force was a function of time. Hence for each measurement, ten continuous readings were taken and their mean was used in calculations.



BALANCE AS VIEWED FROM THE FRONT



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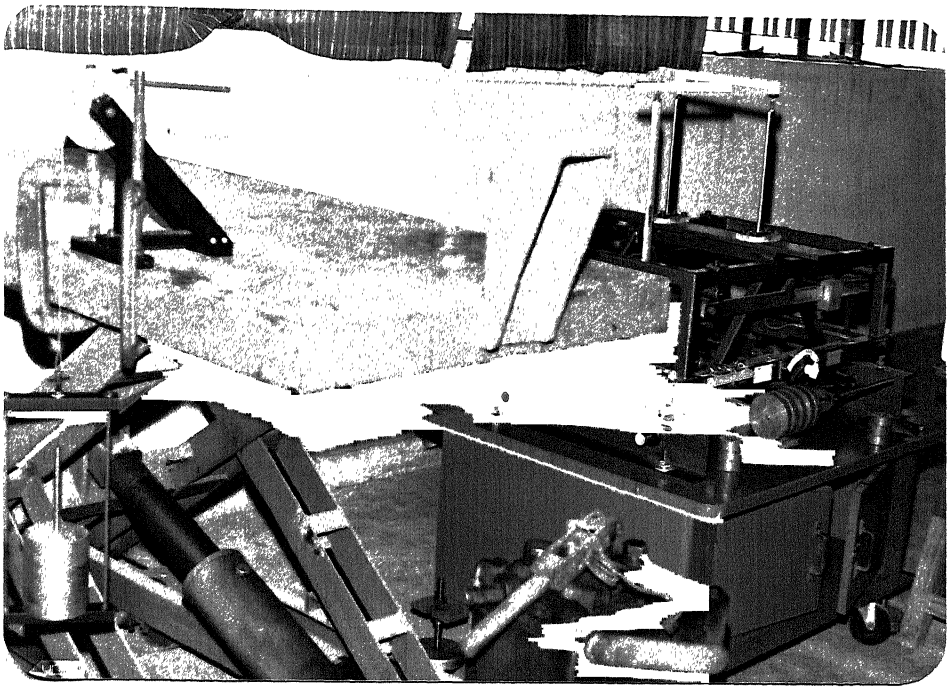

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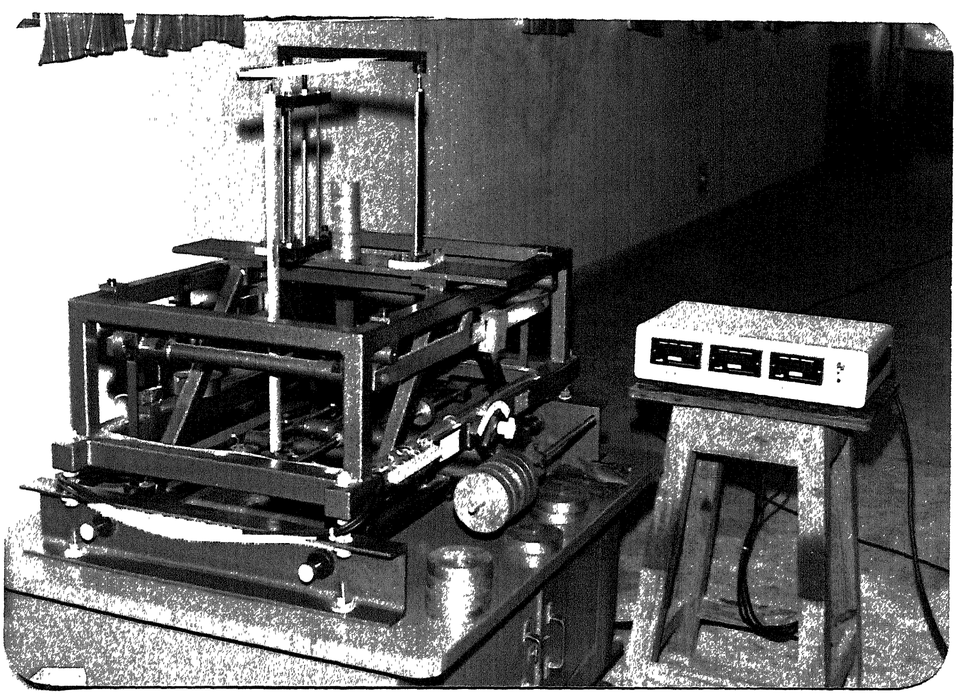
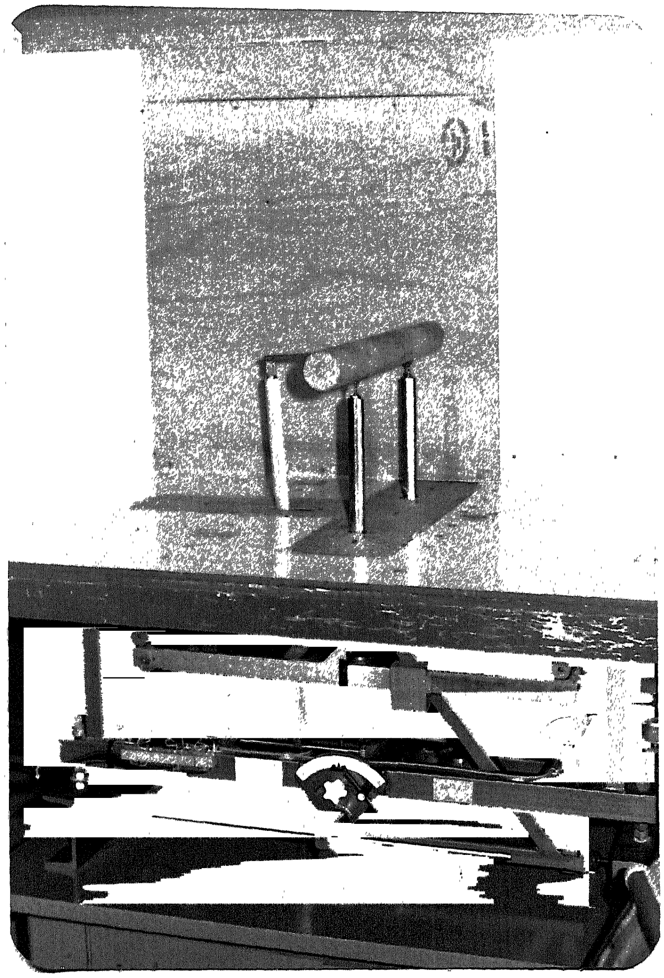
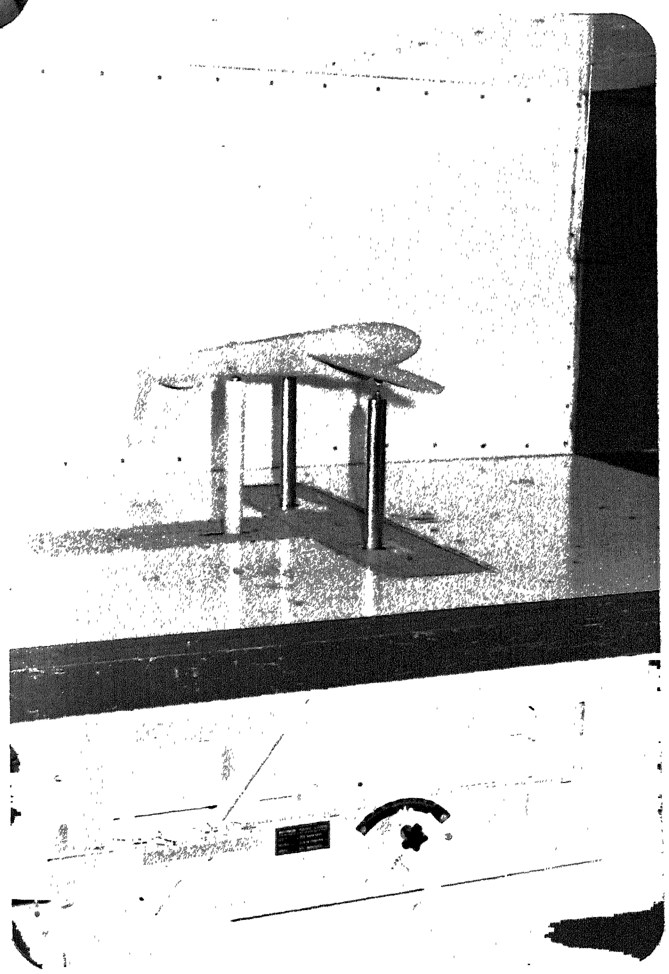


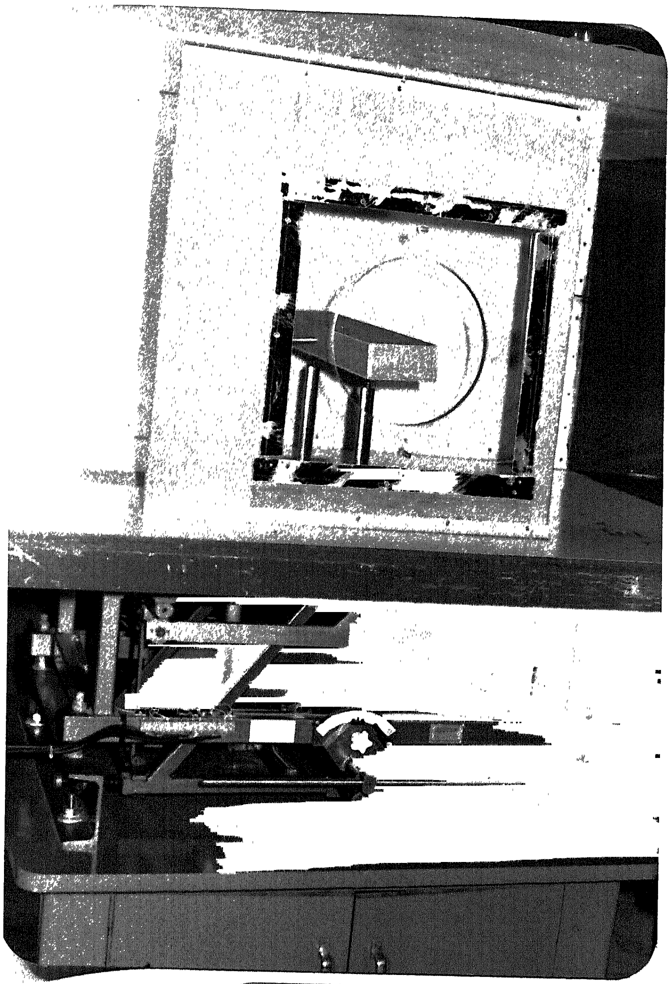
PITCH CALIBRATION



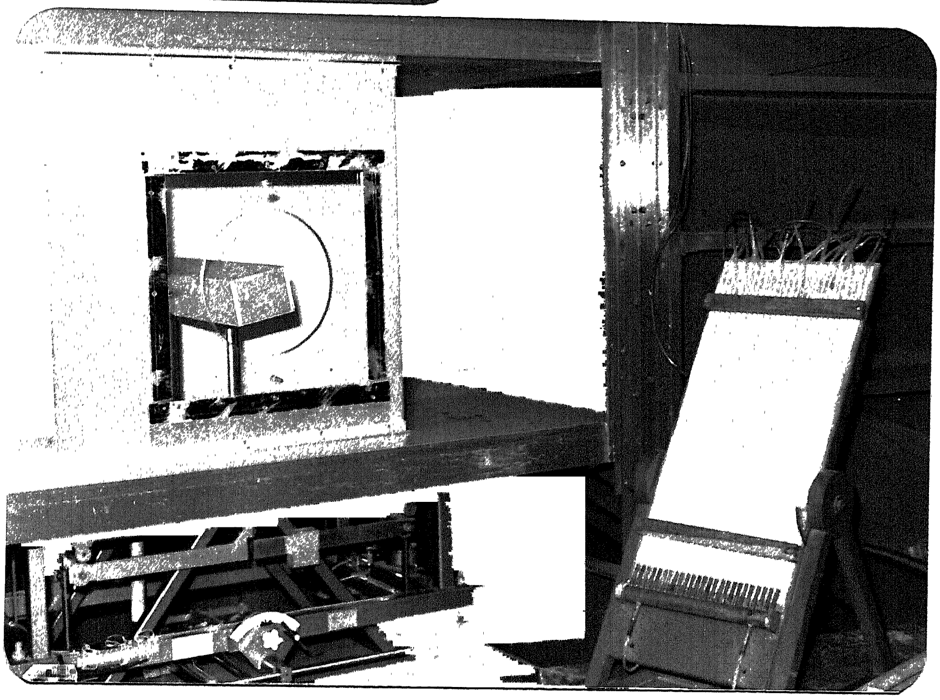
2_D cylinder model
under test (front partition
removed)

Aircraft model under test

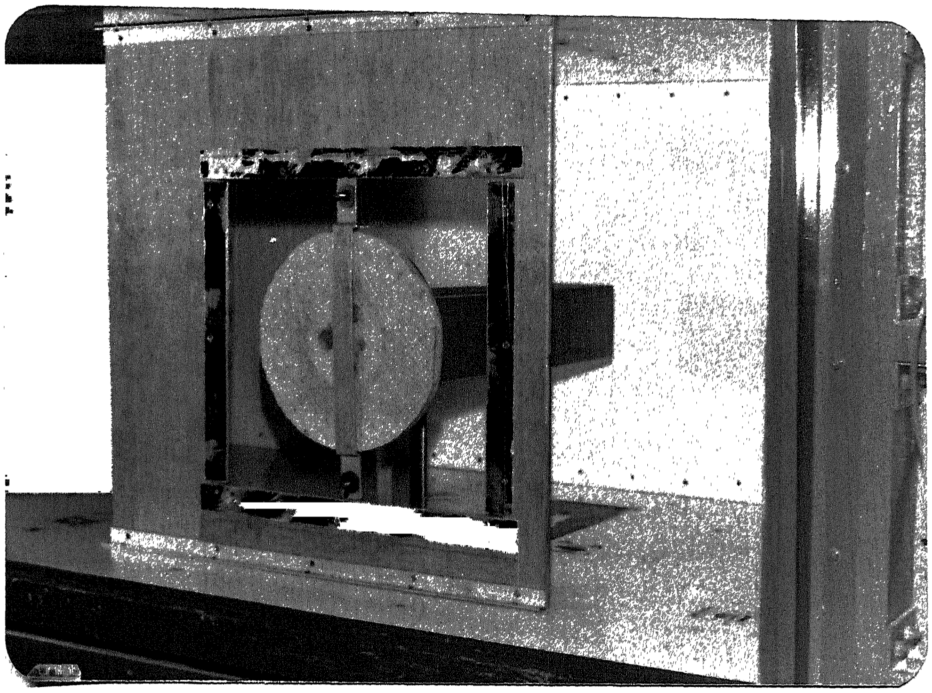




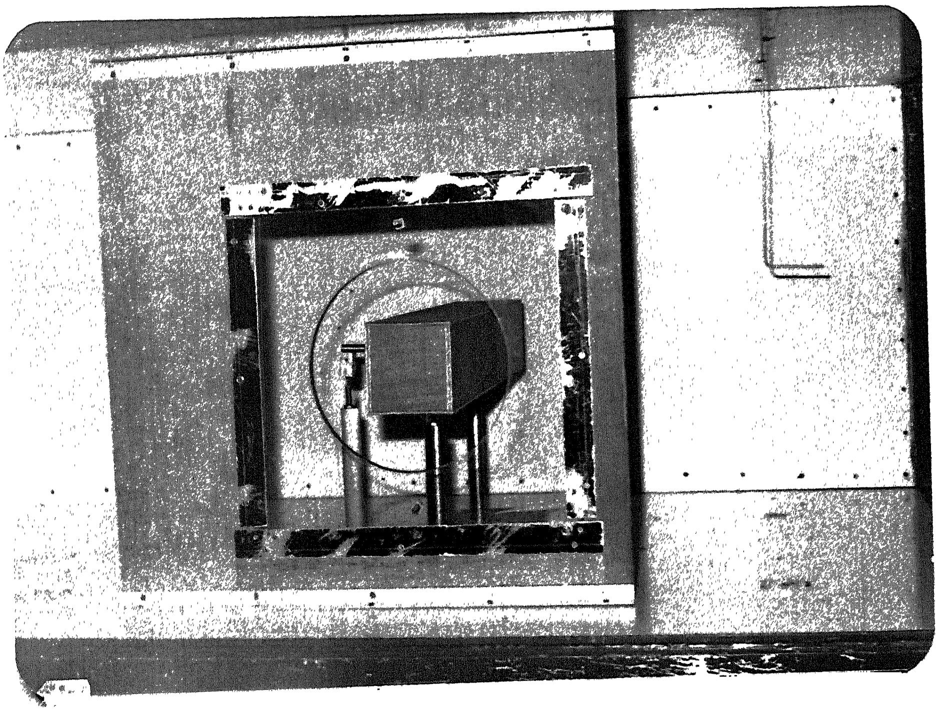
Building model of breadth 5 cm under test.



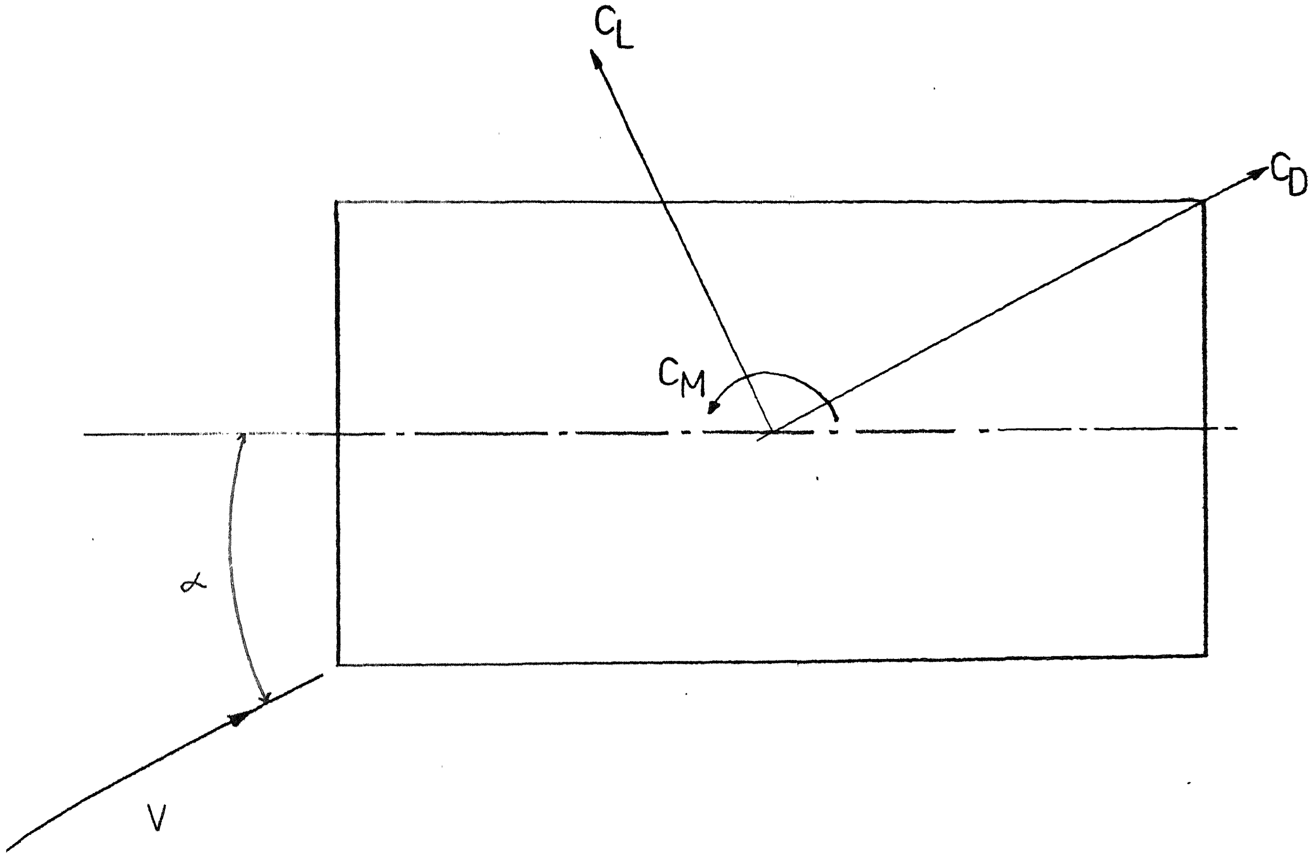
Building model of breadth 7.5 cm with manometer



BUILDING MODEL OF SQUARE CROSS-SECTION UNDER TEST

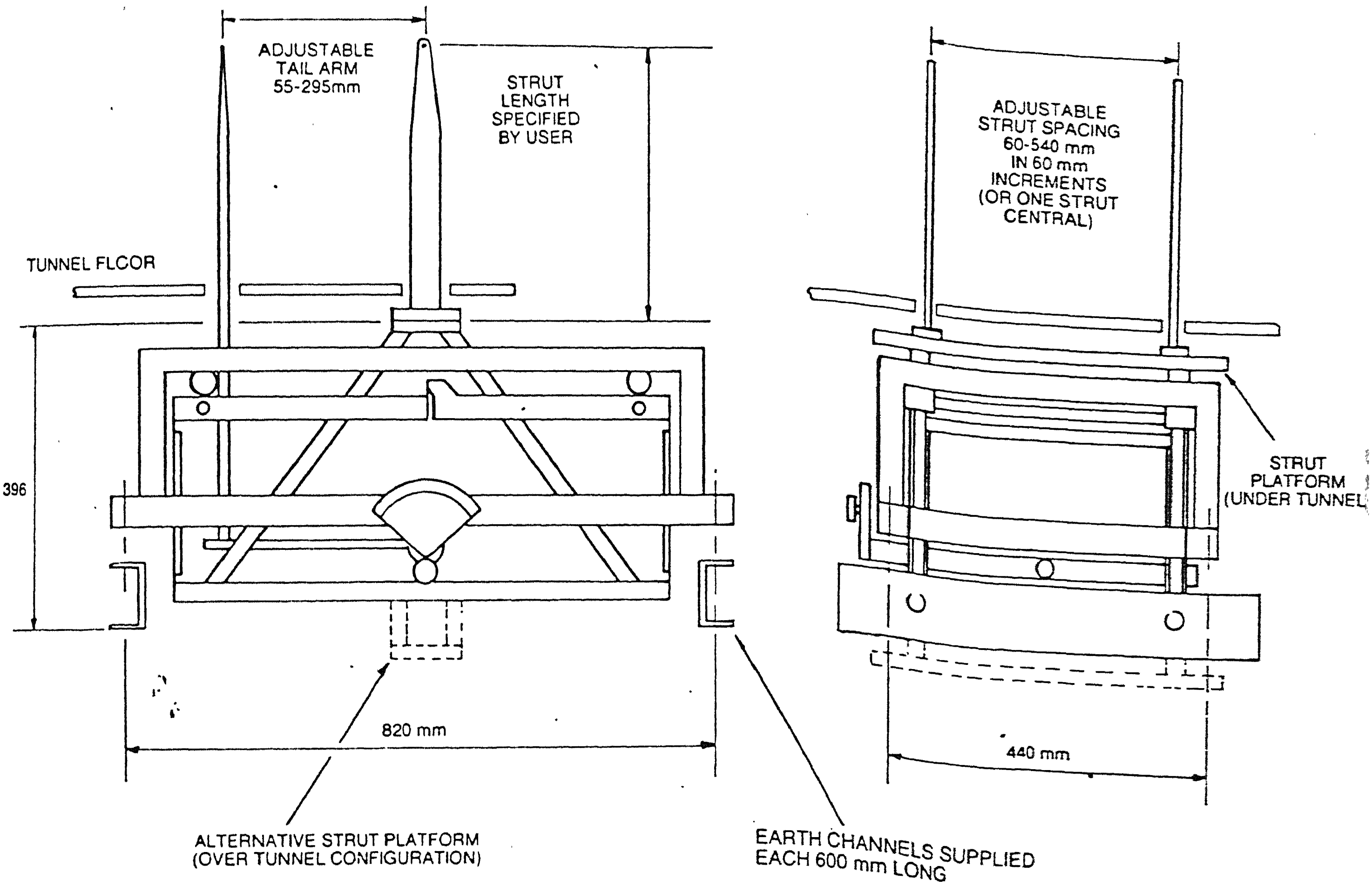


ANOTHER VIEW OF BUILDING MODEL WITH SQUARE CROSS-SECTION



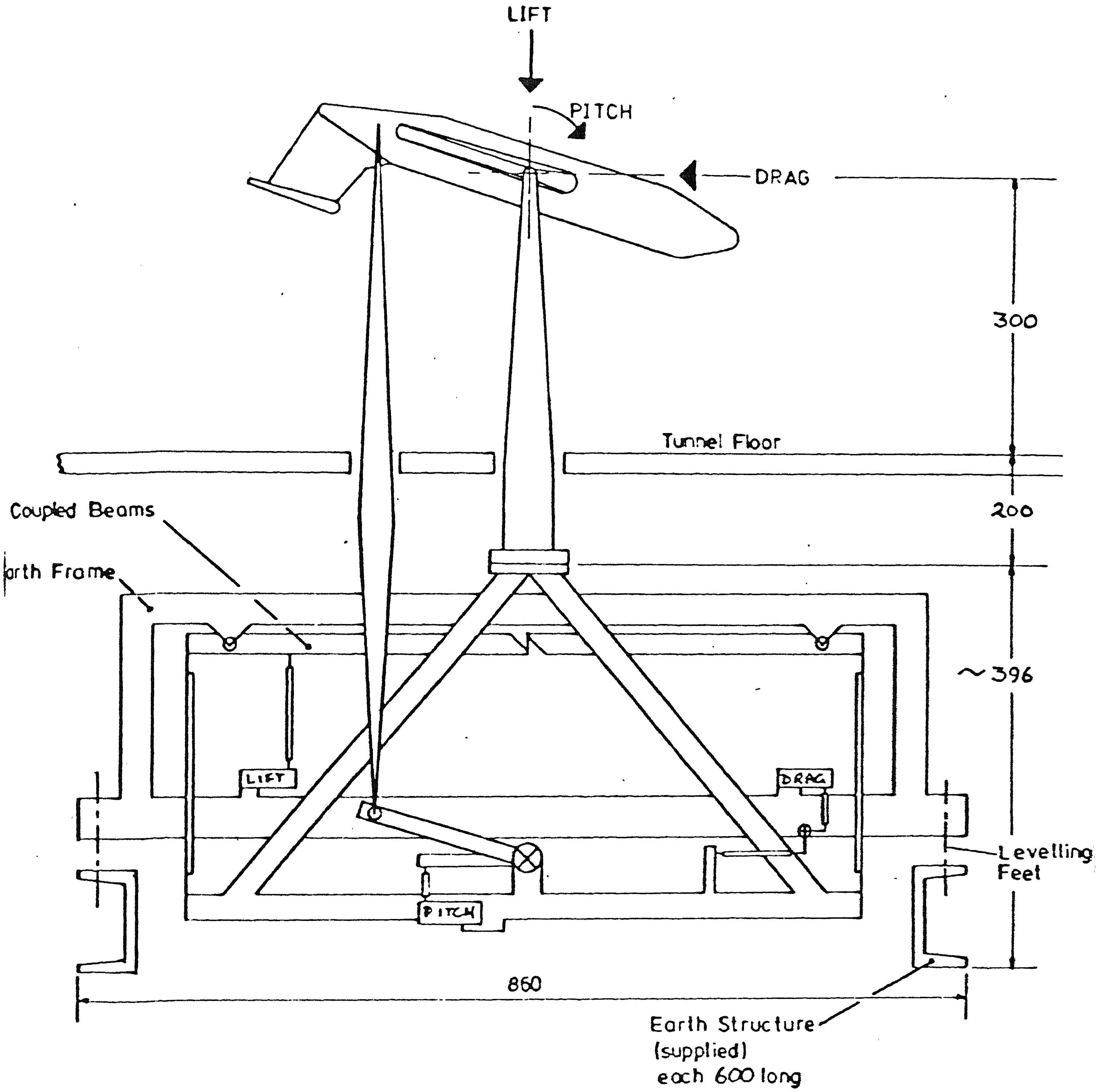
DIRECTION OF FORCES

Fig.1



A SCHEMATIC VIEW OF THE BALANCE

FIG. 2



Schematic Side View and Installation Details.

FIG. 3

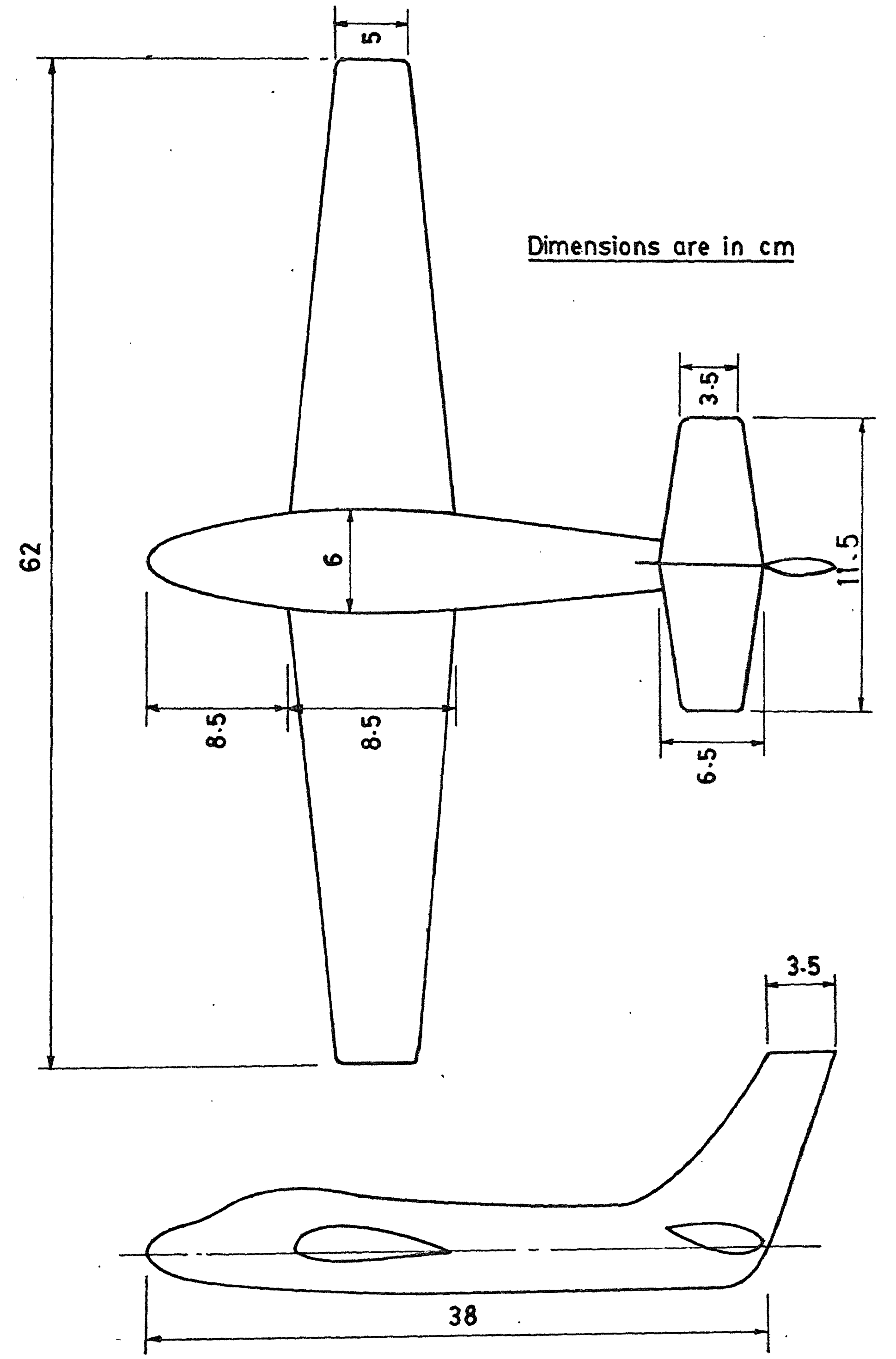
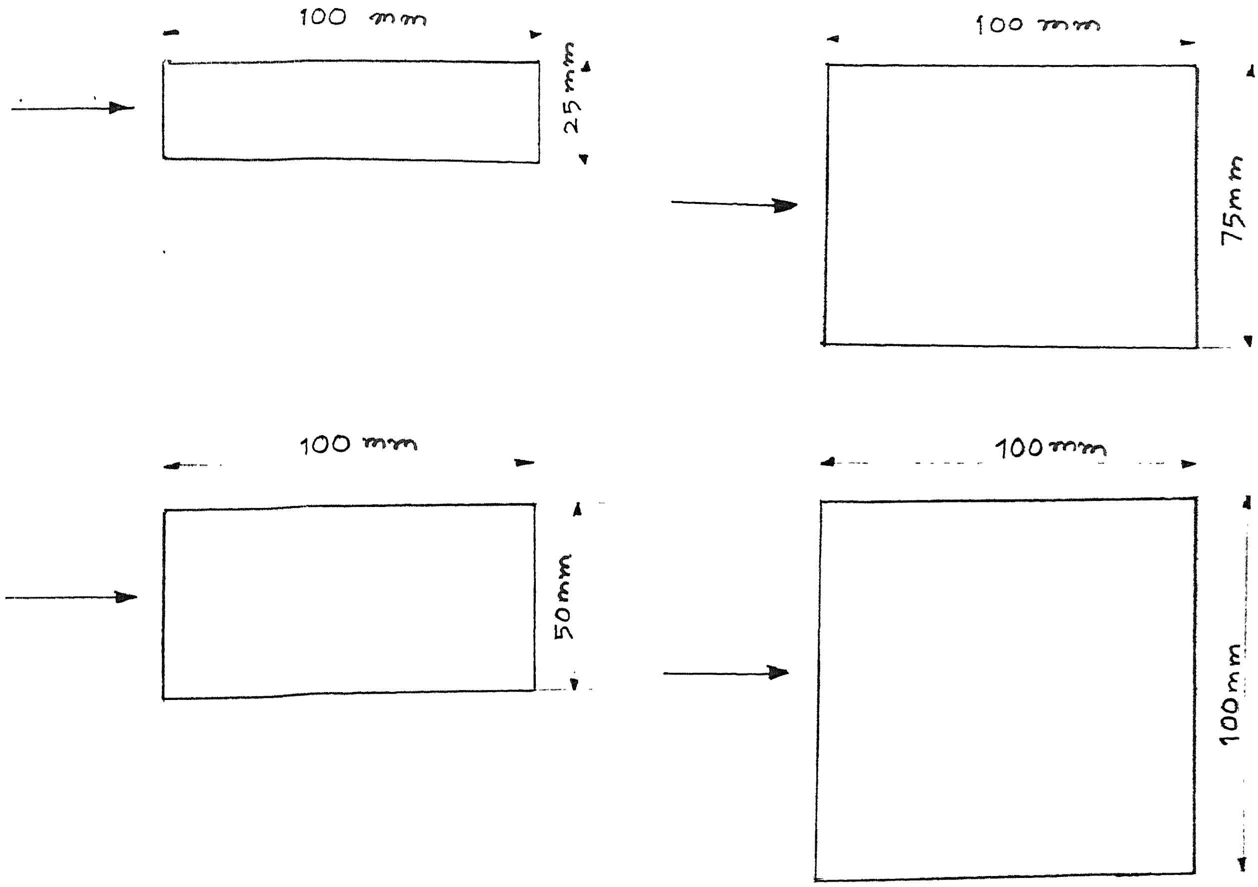


FIG.4 SKETCH FOR AIRCRAFT MODEL



MODEL CROSS SECTION
(Arrow indicates flow direction)

Fig. 5.

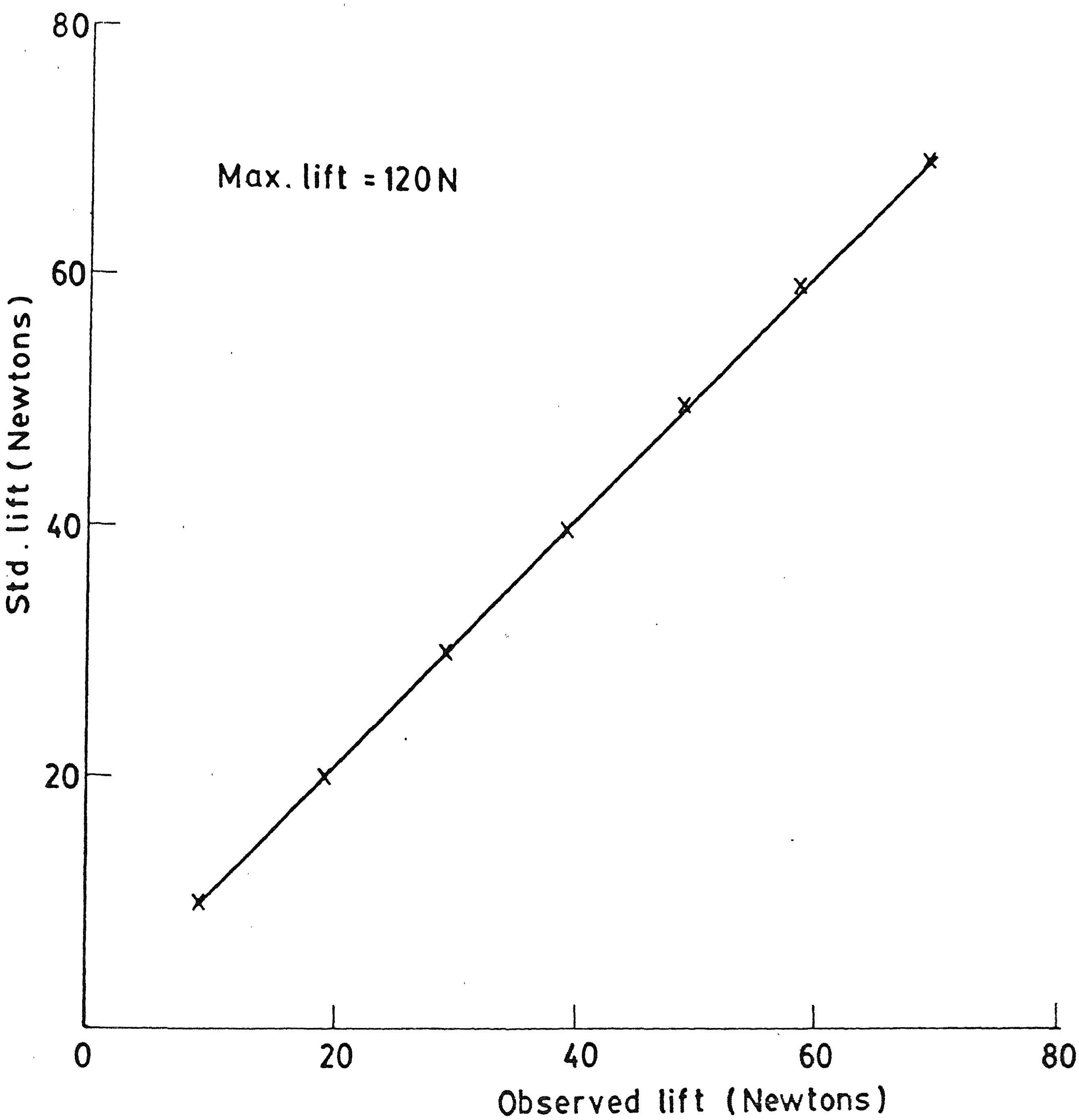


FIG. 6 LIFT CALIBRATION CURVE

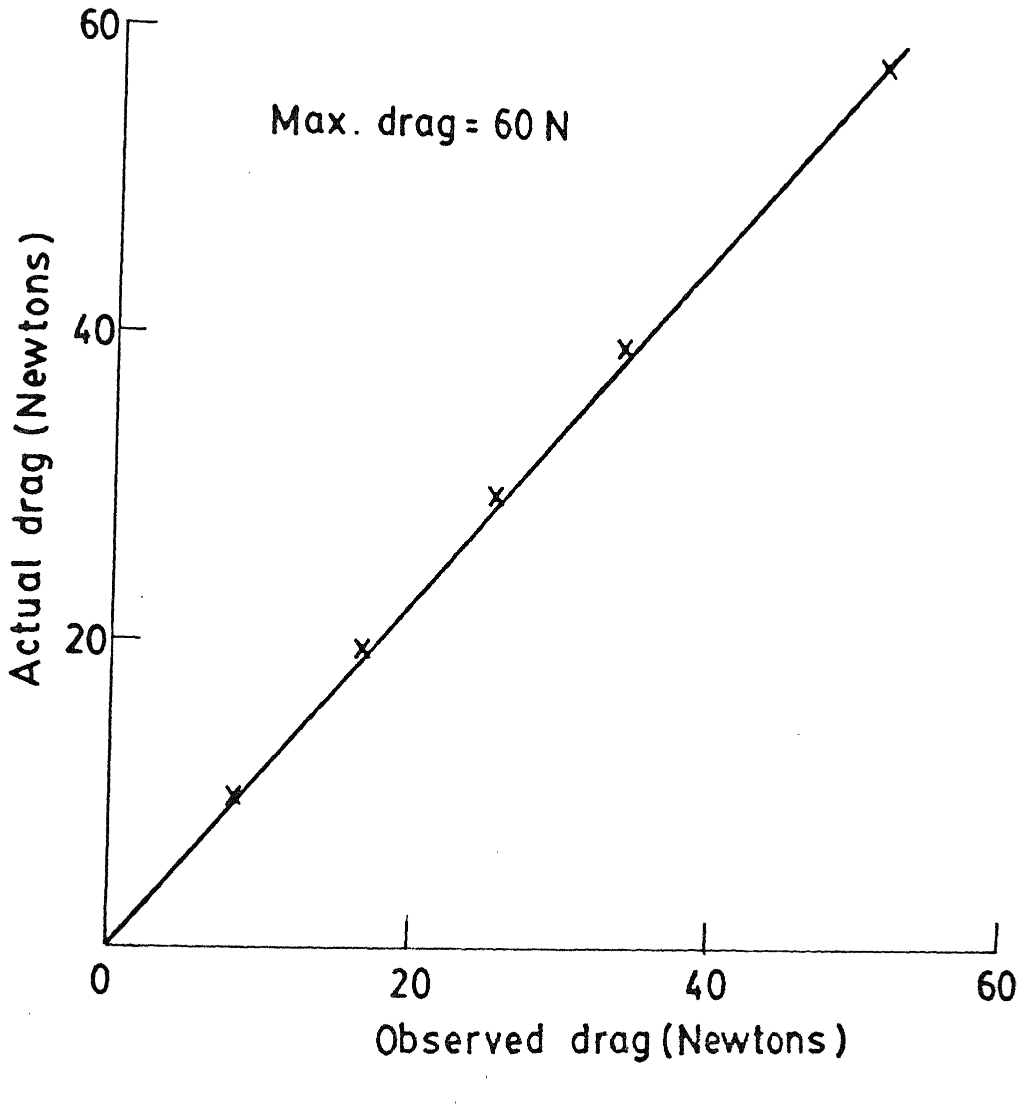


FIG. 7 DRAG CALIBRATION CURVE

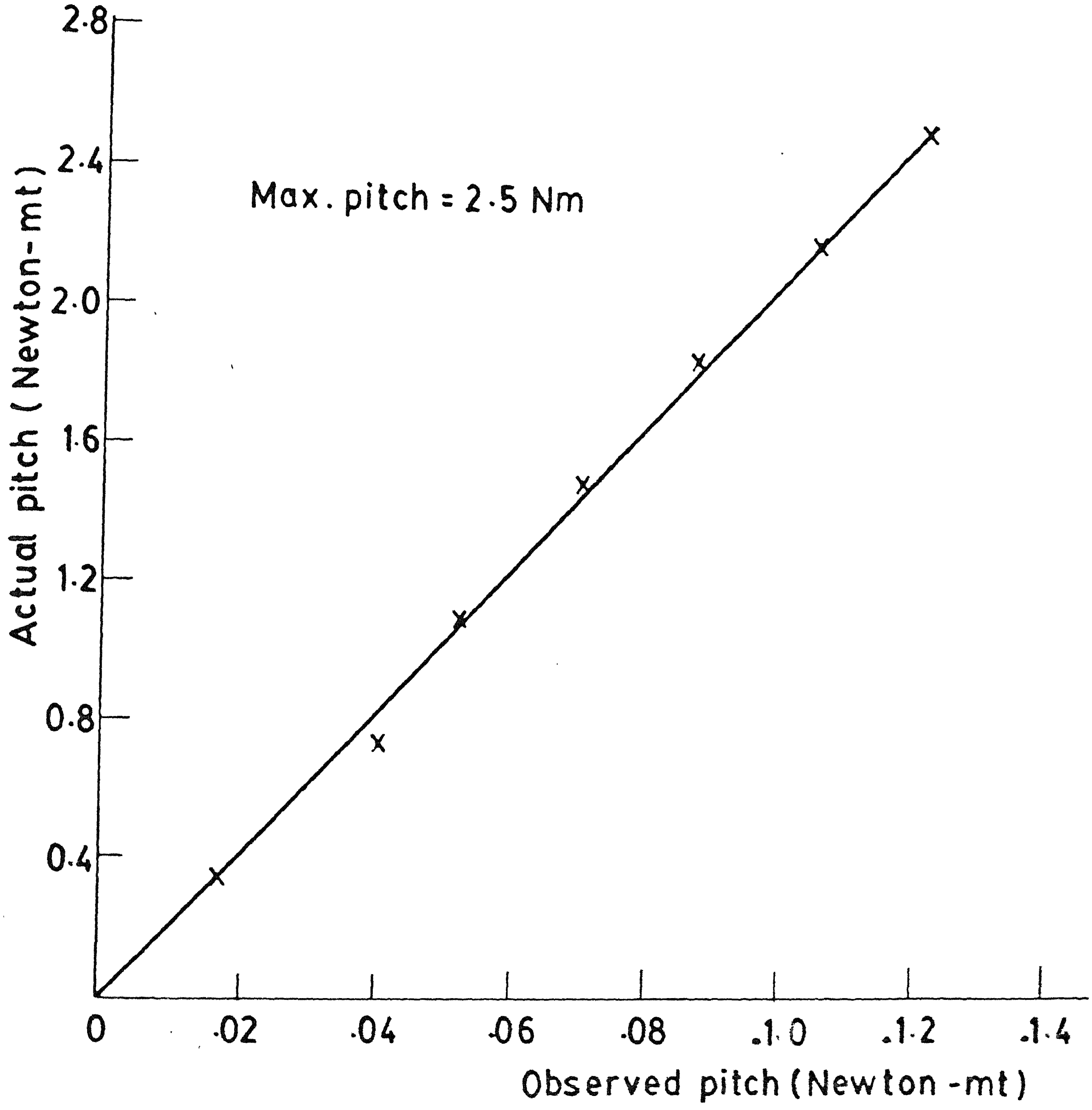


FIG. 8 PITCH CALIBRATION CURVE

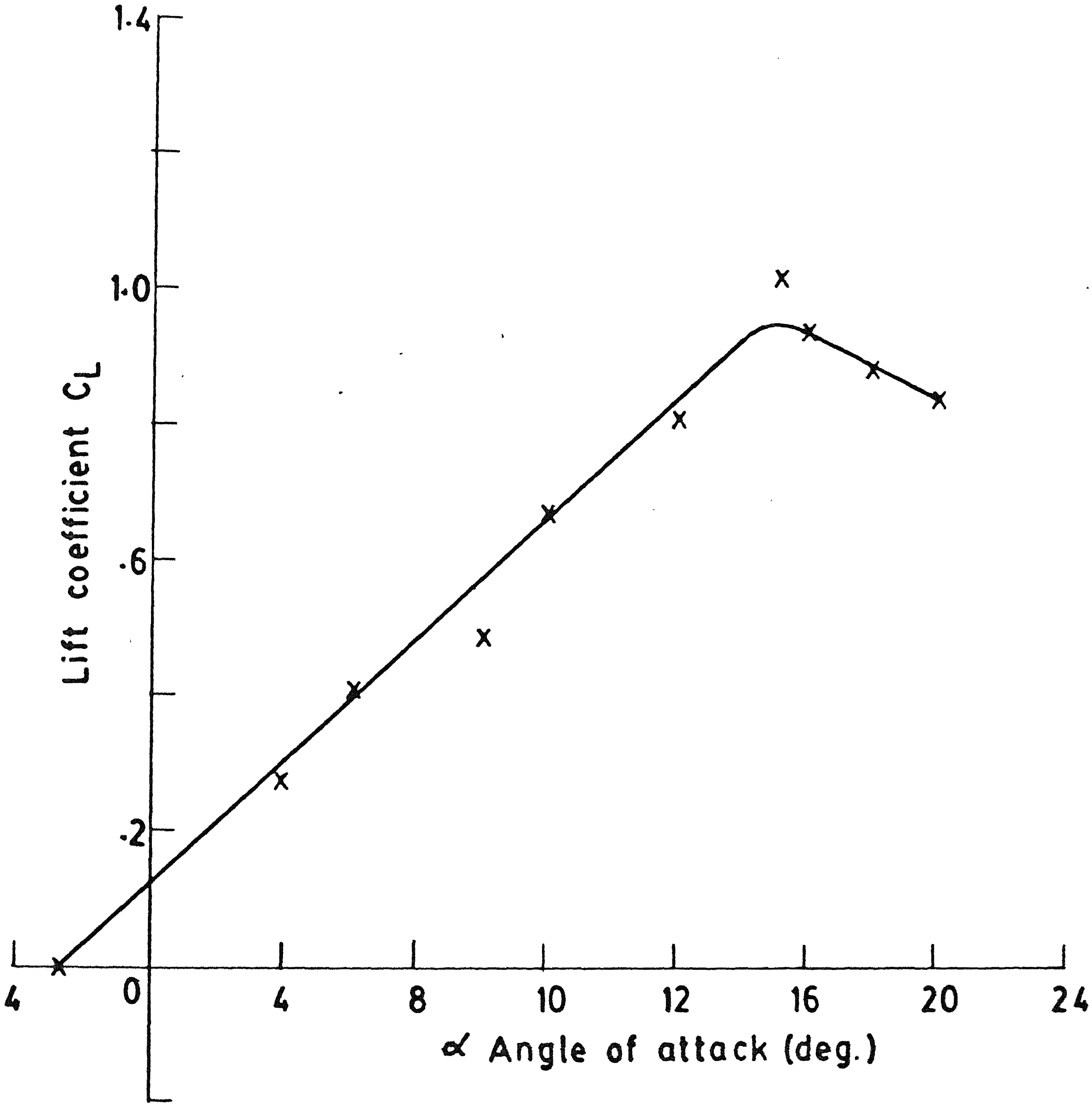


FIG. 9 LIFT CURVE FOR AIRCRAFT MODEL

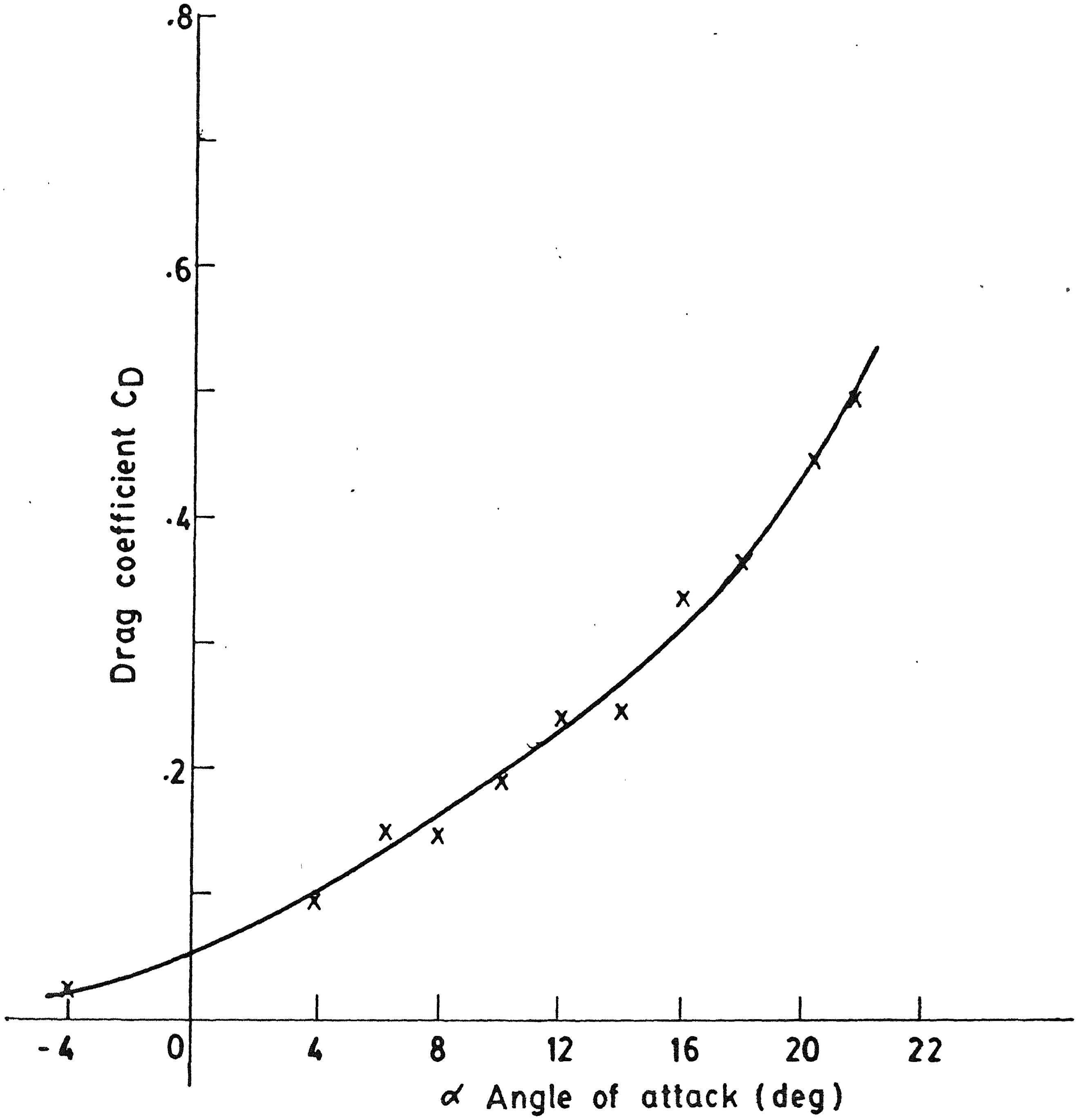


FIG. 10 DRAG CURVE FOR AIRCRAFT MODEL

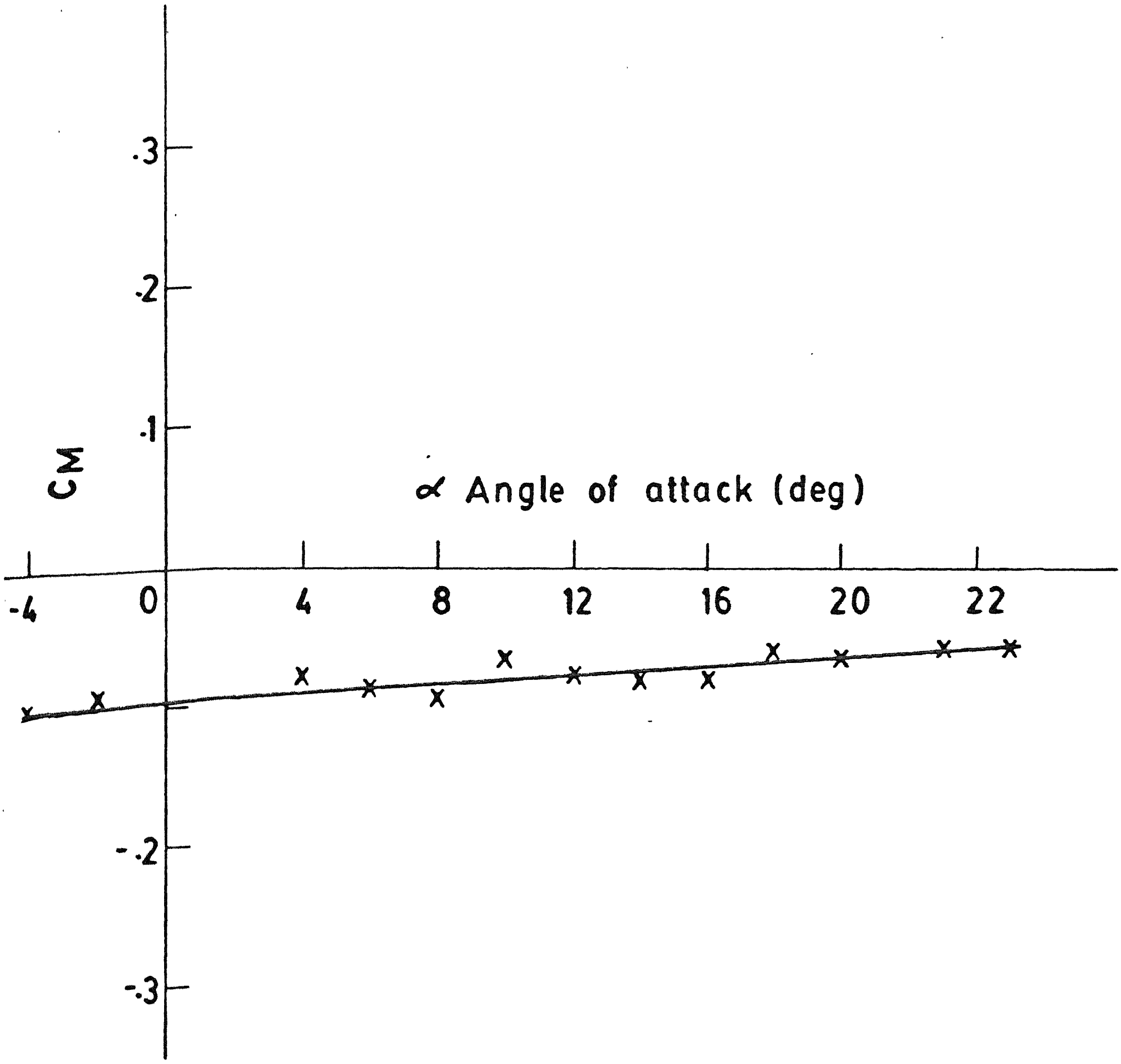


FIG. 11 PITCHING MOMENT CURVE FOR AIRCRAFT MODEL

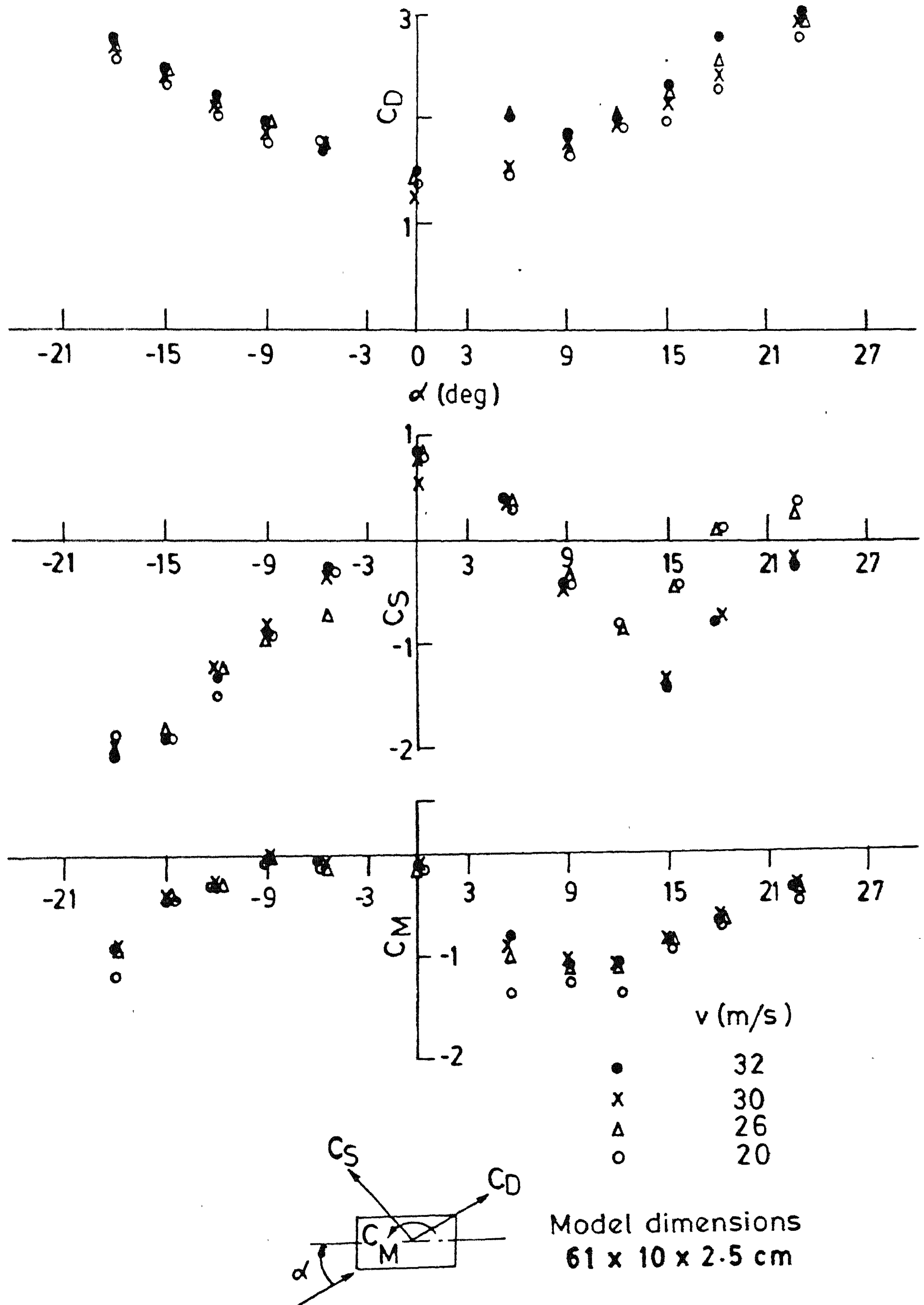


FIG. 12 AERODYNAMIC FORCE AND MOMENT COEFFICIENTS FOR MODEL OF BREADTH = 2·5 cm

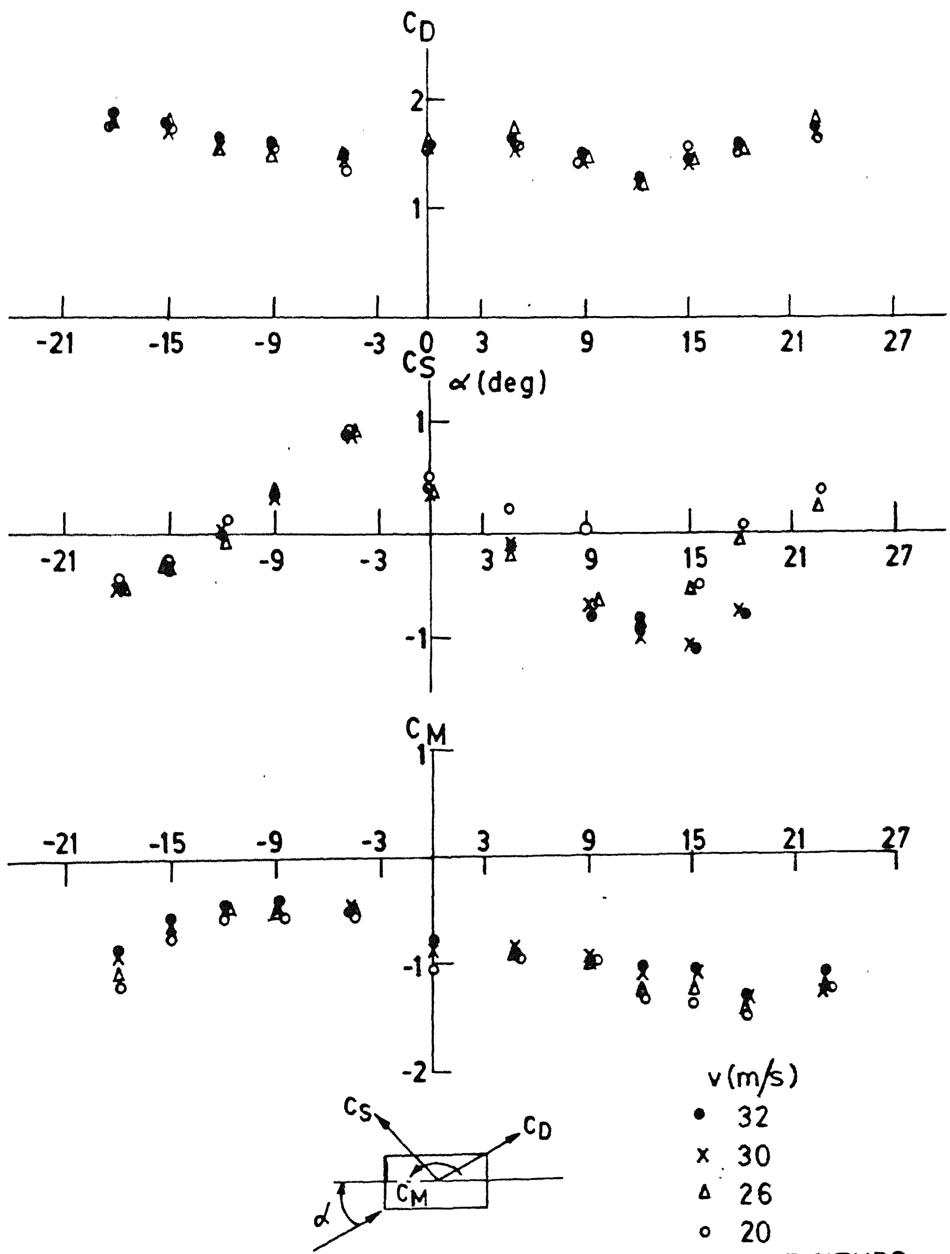


FIG.13 AERODYNAMIC FORCE AND MOMENT COEFFICIENTS FOR MODEL OF BREADTH=5.0 cm

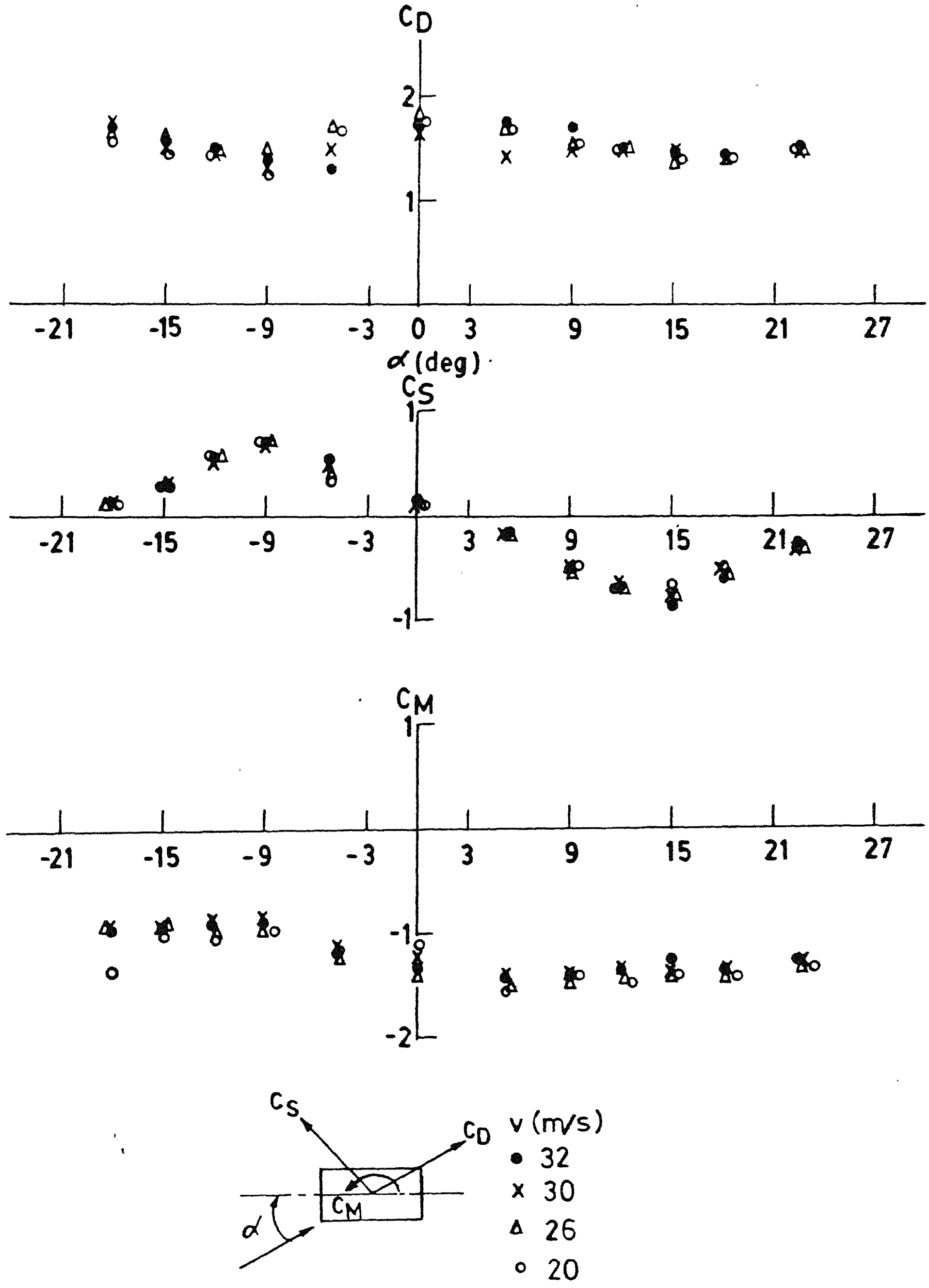


FIG. 14 AERODYNAMIC FORCE AND MOMENT COEFFICIENTS FOR MODEL OF BREADTH= 7.5 cm

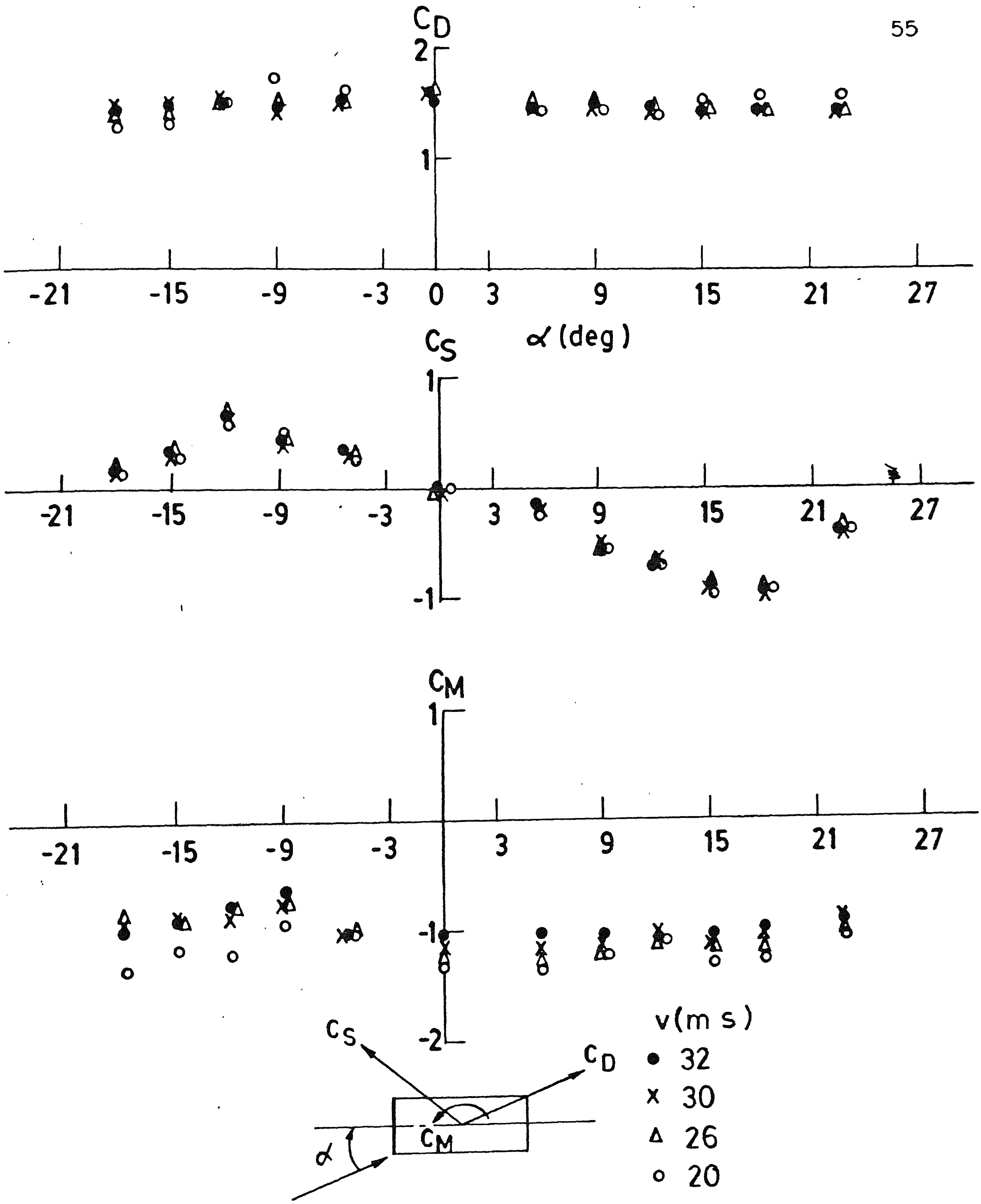


FIG. 15 AERODYNAMIC FORCE AND MOMENT COEFFICIENTS FOR MODEL OF BREADTH=10.0 cm

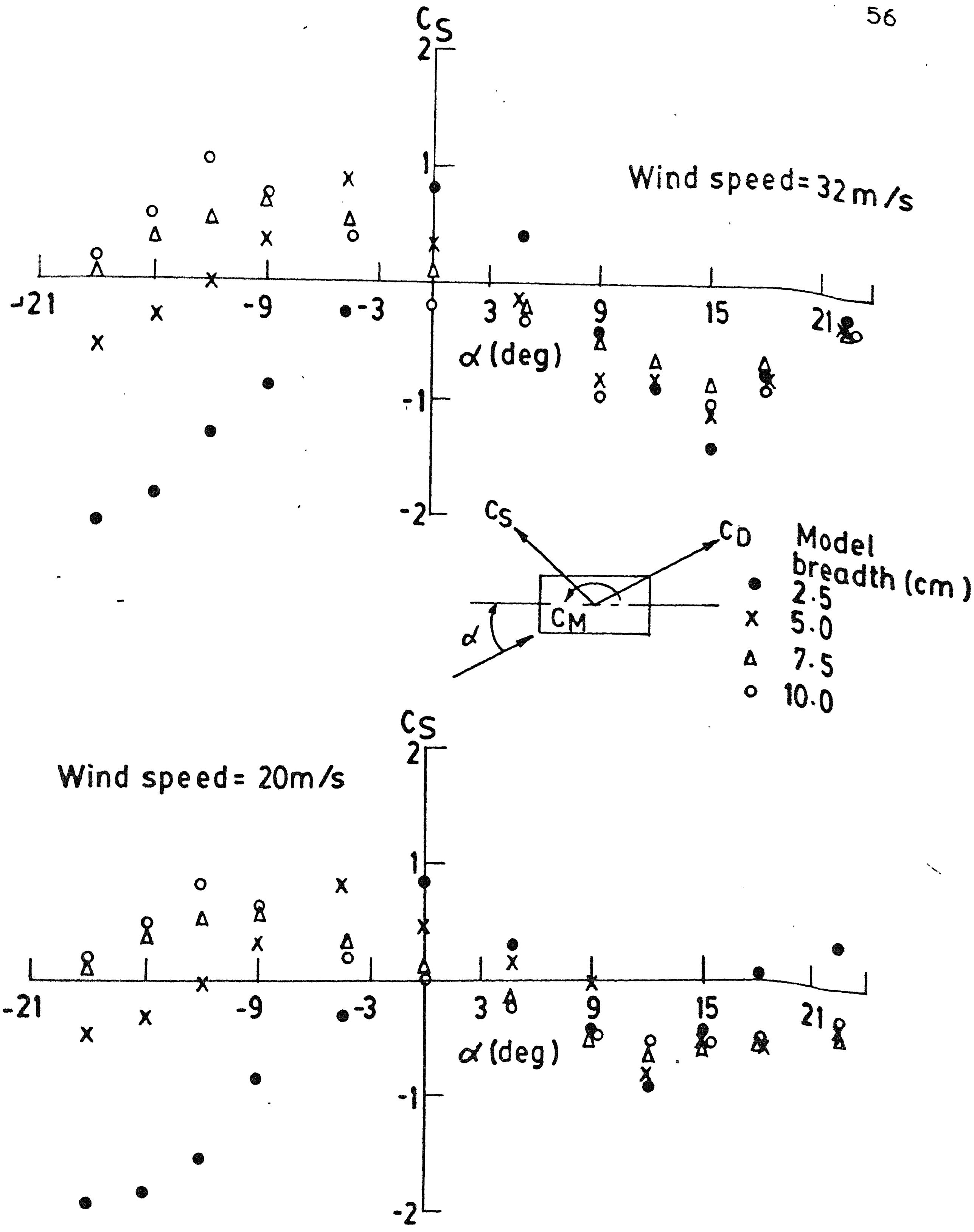


FIG. 16 VARIATION OF SIDE FORCE COEFFICIENT WITH ANGLE OF ATTACK

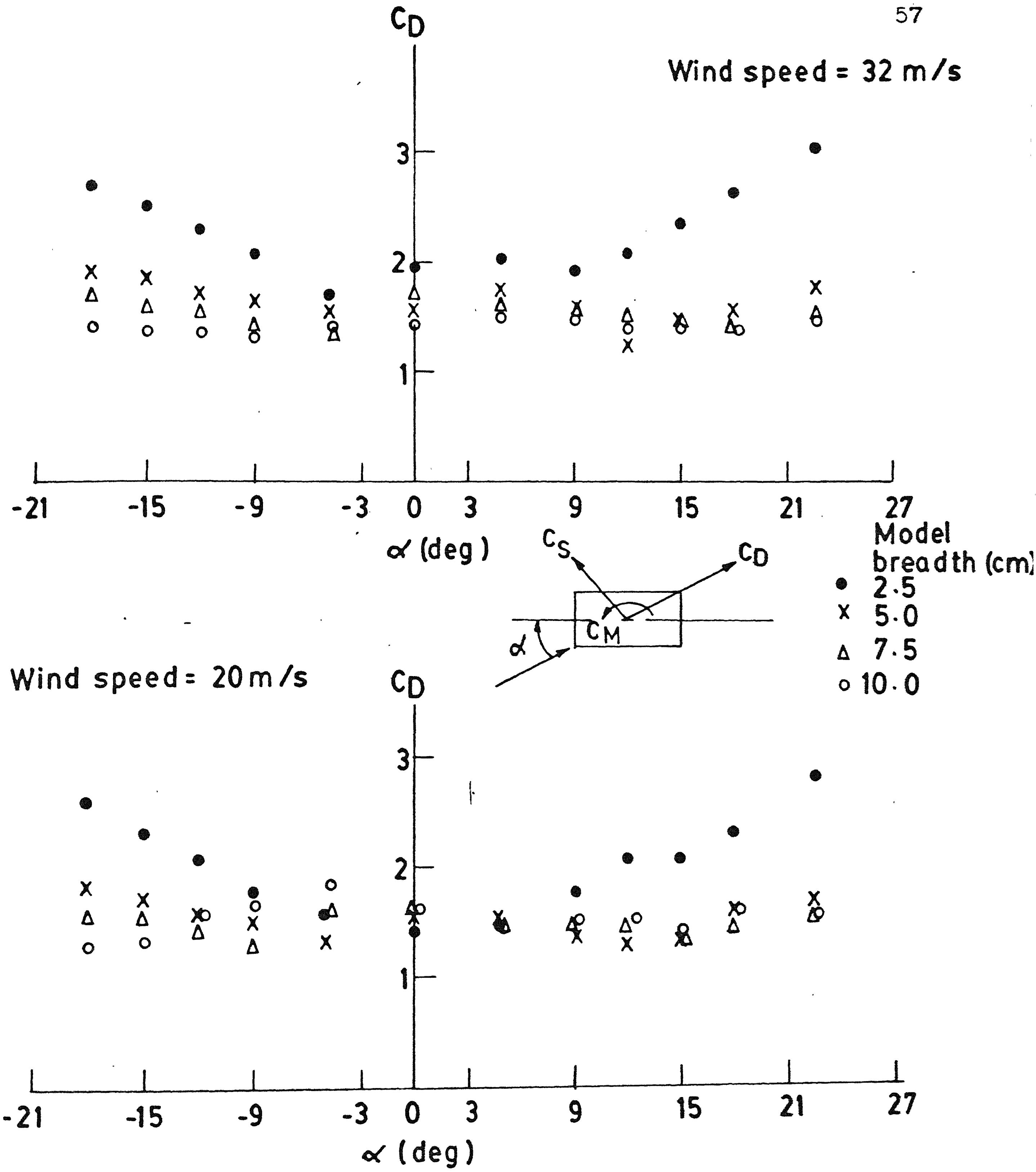


FIG. 17 VARIATION OF DRAG COEFFICIENT WITH ANGLE OF ATTACK

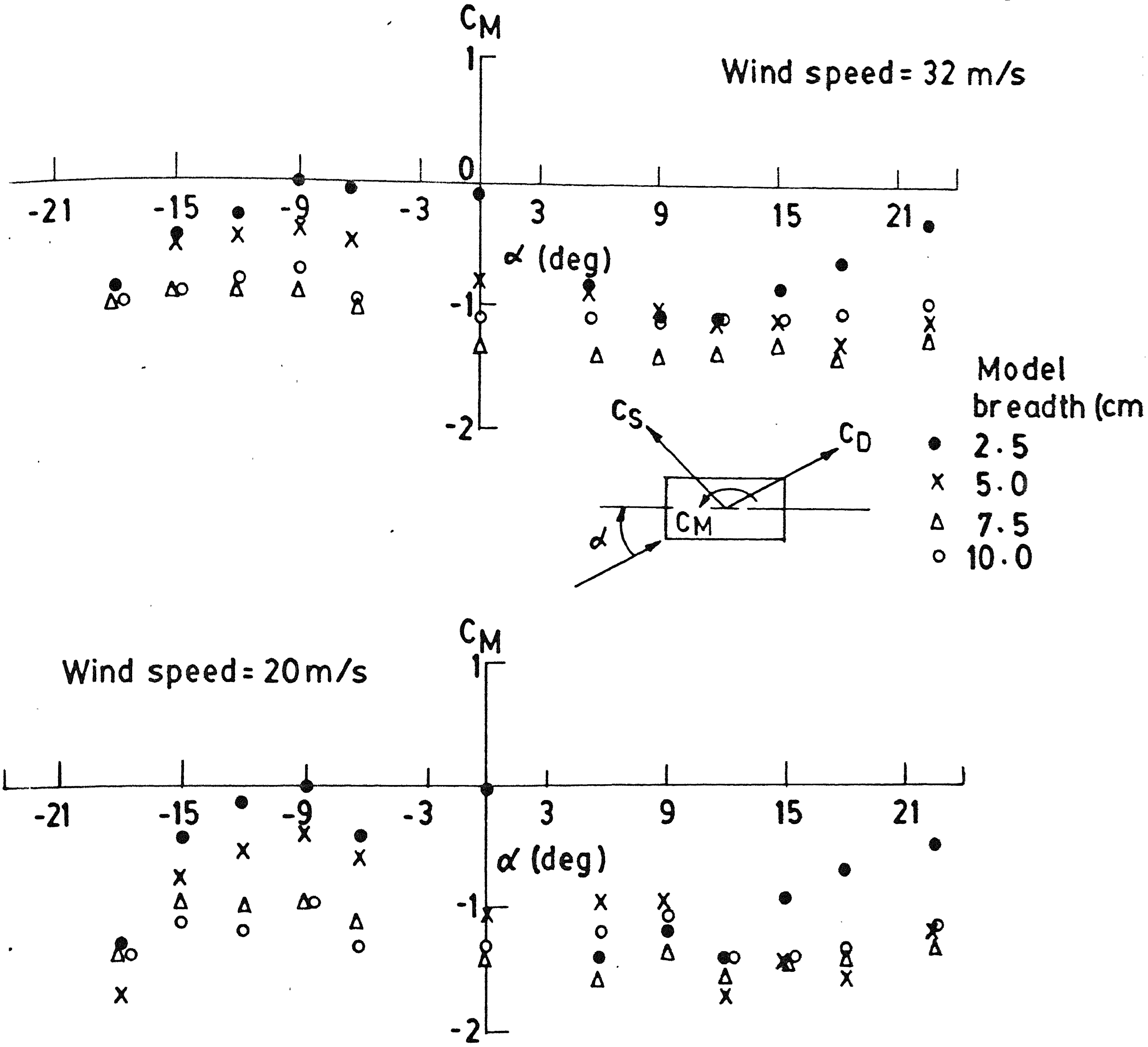


FIG. 18 VARIATION OF PITCHING MOMENT COEFFICIENT WITH ANGLE OF ATTACK

APPENDIX 1

DRAG COEFFICIENT FOR CYLINDER

The cylinder used for the test had a diameter of 0.051 m and span of 0.58 m . It was provided with a small tail to provide the bracket for attachment with the third strut. To make the cylinder two - dimensional, two partitions were put up in the test section of the wind tunnel . In between the two partitions was placed the cylindrical model.

The tests were conducted and following results were determined:

Reynold's number : 10^5

$C_D = 1.4$

$C_L = 0.012$

The results compared well with the standard data .

APPENDIX 2

STUDY OF LIFT AND DRAG FORCES, AND PITCHING MOMENT OF AIRCRAFT

To study the forces and pitching moment on the aircraft a 3- point balance was used. The model was mounted upside down as the Lift force is measured positive by the balance when it is acting in the downward direction. Two struts were attached to the upper side of the wings and the third one was placed just in front of the vertical tail. The readings were taken at varying angle of attack. The results are shown in fig.9-11 . Drag coefficient is large for aircraft model. The reason for this is perhaps increased skin friction because of the surface of model not being very even.

APPENDIX 3

MEASUREMENT OF TURBULENCE USING HOT WIRE ANEMOMETERY

Turbulence in the test section was measured using the hot wire anemometery technique. The results are as reproduced below:

Wind Velocity (m/s)	Percentage of turbulence
32	0.86
30	0.90
26	0.85
22	0.86
18	0.83